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R and D CENTER LABORATORY TECHNICAL REPORT

NO. 12999

U.S. ARMY TACOM

MANUFACTURING PROCESS FOR PRODUCTION OF COMPOSITE LEAF SPRINGS FOR 5-TON TRUCK

JUNE 1984

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20040106090

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) 12999
6a. NAME OF PERFORMING ORGANIZATION CIBA-GEIGY CORPORATION 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 10910 Talbert Avenue Fountain Valley, CA 92708	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S.Army Tank-Autom. Comm. 8b. OFFICE SYMBOL (If applicable) DRSTA-RCKM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAE07-81-C-4064
8c. ADDRESS (City, State, and ZIP Code) Warren, Michigan 48090	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Manufacturing Process for Production of Composite Leaf Springs for 5-Ton Truck. Unclassified

12. PERSONAL AUTHOR(S)
Anderson, Rune N.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
final	FROM 7/81 TO 6/84	June 1984	156

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Composite Materials Truck-Automotive Components Resin Matrix Composites (over)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The objective of this program was to design leaf springs for the Army 5-ton truck using composite materials and to establish the best manufacturing process for producing the springs in modest quantities (25 sets of spring assemblies per day), while maintaining consistent material properties. Ten rear spring assemblies (Phase I) and ten front spring assemblies (Phase II) were fabricated from the established process.

Steel leaves were used in combination with fiberglass/epoxy leaves. The steel leaves assures interchangability with the existing all steel leaf springs. S-2 glass fiber was used in the composite leaves to meet the performance requirements.

(over)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. The results of the design study, material selection, and fabrication process evaluation are included in the report. A description of the fabrication process utilized in making prototype parts is included as well as an economic analysis for producing composite leaf springs in large quantities.

18. Manufacturing Process Composites
Fiberglass-Epoxy
Leaf Springs

PREFACE

This report covers the work performed under Phase I and Phase II of Contract DAAE07-81-C-4064. This project was initiated under the Manufacturing Methods and Technology program. The contract was monitored initially by Dr. Robert Ellis, and, after December 1982, by Mr. Donald Ostberg, AMSTA-RCKM of the US Army Tank-Automotive Command, Warren, Michigan.

Composite Materials Department of CIBA-GEIGY Corporation (formerly Riggs Engineering) was the prime contractor for this program with some of the composite parts being manufactured under sub-contract by Dittmer & Dacy, Inc., of San Diego, California.

The project was managed for CIBA-GEIGY, CMD by Rune N. Anderson.

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1. Introduction and Background

The feasibility of producing composite material leaf springs for automotive applications has been demonstrated in the industry. Various manufacturing processes have been utilized, generally for producing prototype springs in small quantities.

When designing with composite, orthotropic materials the interrelationship between materials, configuration, manufacturing methods, cost and quality assurance must be considered to a much larger degree than is generally the practice with conventional materials such as metals. One reason for this is that the material is processed to its final form (cured) at the same time the part is being fabricated. Of particular importance is a design which is cost-effective and at the same time allows the use of manufacturing methods whereby consistently reproducible, high material properties can be assured.

The program called for a study to establish a manufacturing process suitable for producing composite material, heavy duty, leaf springs in modest quantities.

The Army had initially intended that the manufacturing study be conducted on an existing composite spring design developed under an earlier contract by EXXON Enterprises, Materials Division. Reconfiguration was to be limited to that necessary to the development of the manufacturing process. However, load and deflection requirements listed in the contract document showed a significant increase over the earlier design, necessitating an entirely new design.

A fatigue study showed that E-glass fiber/epoxy material would not give a sufficient life to the spring. Therefore, S2-glass fiber was selected. A combination of graphite and glass fibers in a sandwich configuration was considered, but was rejected because of the high cost of graphite fiber.

The study further showed that only leaves with tapered thickness would meet both envelope and weight requirements. The requirement for a tapered thickness eliminated some of the candidate manufacturing processes.

The program was divided into two phases. Phase I addressed the design and manufacture of the rear spring assembly, while Phase II did likewise for the front spring assembly. This report covers work performed under both Phase I and Phase II.

2. Purpose and Objectives

The objective of this program was to design leaf springs for the Army 5-ton trucks using composite materials and to establish the best manufacturing process for producing the springs in modest quantities (25 sets of spring assemblies per day), while maintaining consistent material properties. Ten rear spring assemblies (Phase I) and ten front spring assemblies (Phase II) were fabricated from the established process and delivered to TACOM for testing and evaluation.

3. Fatigue Load Study

Automotive leaf springs are subjected to bending deflections, and, in some cases, torsional loads which, during the life of the vehicle, impose repeated stresses on the spring material. Since practically all materials lose some of their initial strength by repeated loading, it is necessary for the design engineer to know both the load cycle requirements and the degree of material degradation.

Therefore, before any design activity or material selection could be initiated, it was necessary to establish fatigue requirements for the composite spring.

For that purpose, a study was conducted to determine cycling fatigue life for a number of different design concepts, and for various loading combinations. From the results, the best suitable design concept was then selected jointly by CIBA-GEIGY and TACOM.

Several design configurations were investigated, including leaves with tapered and constant thickness, as well as different materials. Graphite fiber was ruled out because of its high cost. Kevlar is not suited for applications involving predominantly bending stresses, because of its poor compression properties. The study evaluated E-glass fiber/epoxy and S2-glass fiber/epoxy for fatigue properties. CIBA-GEIGY and TACOM jointly selected load cycles (combinations of maximum stress and load ratio R, where R = ratio of minimum to maximum load cycle stress) for the front and rear spring assemblies so as to represent loads encountered in actual service. In evaluating spring configurations, certain limitations had to be observed. The stacked height of the assembled leaves cannot exceed that of the present steel spring. In addition, the total weight of the assembly was constrained by project goals.

3.1 Rear Spring (Phase I)

It was assumed that the two bottom leaves, which provide the attach points to the vehicle, would be made of steel and have a configuration essentially the same as that of the existing steel spring. The remaining leaves would be made from composite materials.

The following design configurations were investigated:

1. E-glass, tapered thickness
2. S2-glass, tapered thickness
3. E-glass, constant thickness
4. S2-glass, constant thickness

The effects of the jointly selected load cycles on fatigue life were investigated for each configuration. Table 3-1 describes the four load patterns used as fatigue design criteria.

The composite rear spring assembly must be designed such that its deflection versus load characteristic duplicates that of the existing all-steel rear spring. The required load/deflection characteristics for the composite spring assembly as a whole, and for the composite leaves alone, are illustrated in Figure 3-1.

Loading Condition	Load Ratio, R (minimum/maximum load)
A. (Static load/2) to full jounce	.16
B. Static load to full jounce	.32
C. (Static load/2) to 2.5 times static load	.20
D. (Static load/2) to 2.0 times static load	.25

Notes:

1. Static load for composite leaves: 10,430 lbs (46,393 N).
2. Full jounce: G.V.W. load deflection + 7.25 inches (184 mm).
3. Load on composite leaves at full jounce: 46,128 lbs (205,177 N).

Table 3-1. Loading Conditions And Ratios For Rear Spring Assembly.

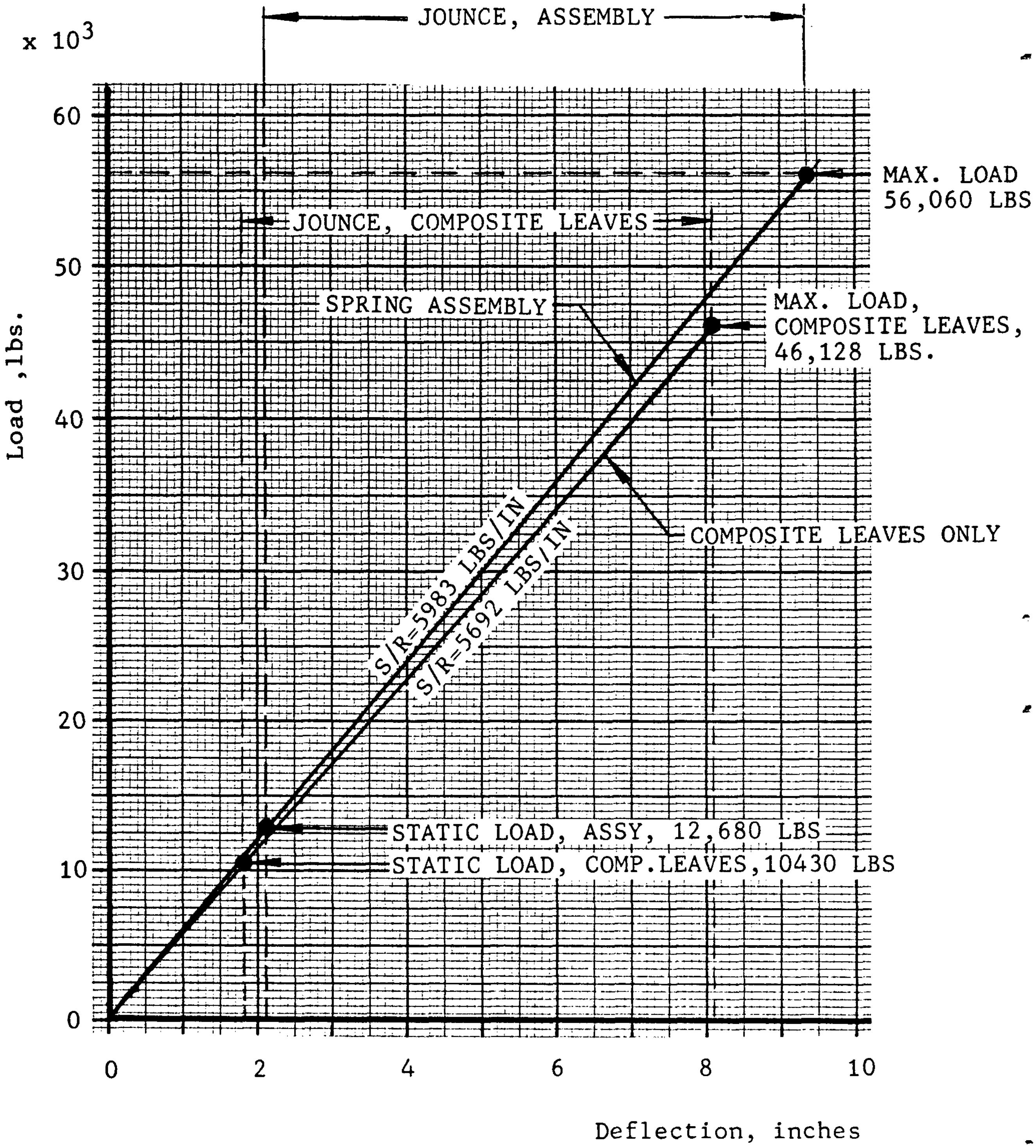


Fig. 3-1. Load/Deflection Diagram, Rear Spring

Figures 3-2 and 3-3 are, respectively, Goodman diagrams for E-glass and S2-glass fiber/epoxy composites in bending. These diagrams present fatigue life characteristics for a given material when subjected to various numbers of loading cycles in which the stress varies between a minimum and maximum value. The horizontal and vertical coordinates represent minimum and maximum stresses expressed as percentage of ultimate flexural (or bending) strength. Two sets of curves are plotted on these coordinates. One set represents constant values of loading cycles expected before failure, while the second set represents constant values of loading ratio. The fatigue characteristics of E-glass and S2-glass epoxy composites, as illustrated in the Goodman diagrams, were used to determine expected life for various combinations of maximum stress and loading ratio. This data is given in Tables 3-2 and 3-3 for E- and S2-glass/epoxy, respectively.

CIBA-GEIGY prepared a computer program to calculate the number of leaves required in a spring assembly for various combinations of required fatigue life, material type, leaf configuration, and loads. Figures 3-4 through 3-7 are graphs of this data for the rear spring. Each figure describes the number of leaves as a function of expected fatigue life for the four load conditions given in Table 3-1. The four figures represent combinations of material (E- or S2- glass) and leaf configuration (constant or tapered thickness). The program also calculated weight and stacked height, and these values are given on the graphs for each data point plotted.

A typical computer printout for tapered thickness rear spring leaves is shown in Figure 3-8, and for constant thickness leaves in Figure 3-9.

The target weight for the composite leaves in the rear spring is 100 lb (45.4 kg), maximum. The stacked height of these leaves must not exceed 6 inches (152.4 mm) so as to remain within the dimensions of the currently used steel spring. From Figures 3-4 through 3-7 and the weight and height constraints, it is apparent that for a fatigue life of 100,000 cycles, constant thickness leaves are acceptable only if S2-glass is used, and, even then, only for the least severe loading combination. Tapered thickness leaves are more efficient in utilizing the strength of a given material. With this configuration, the weaker E-glass will meet the weight/height/fatigue life requirements for the least severe load condition. With S2-glass, tapered leaves can meet these requirements for all four load ratios.

The higher cost of S2-glass (approximately double that of E-glass for prepreg material) is compensated for by the lower total weight of an S2-glass spring. Fabrication cost is also lower because fewer leaves are required.

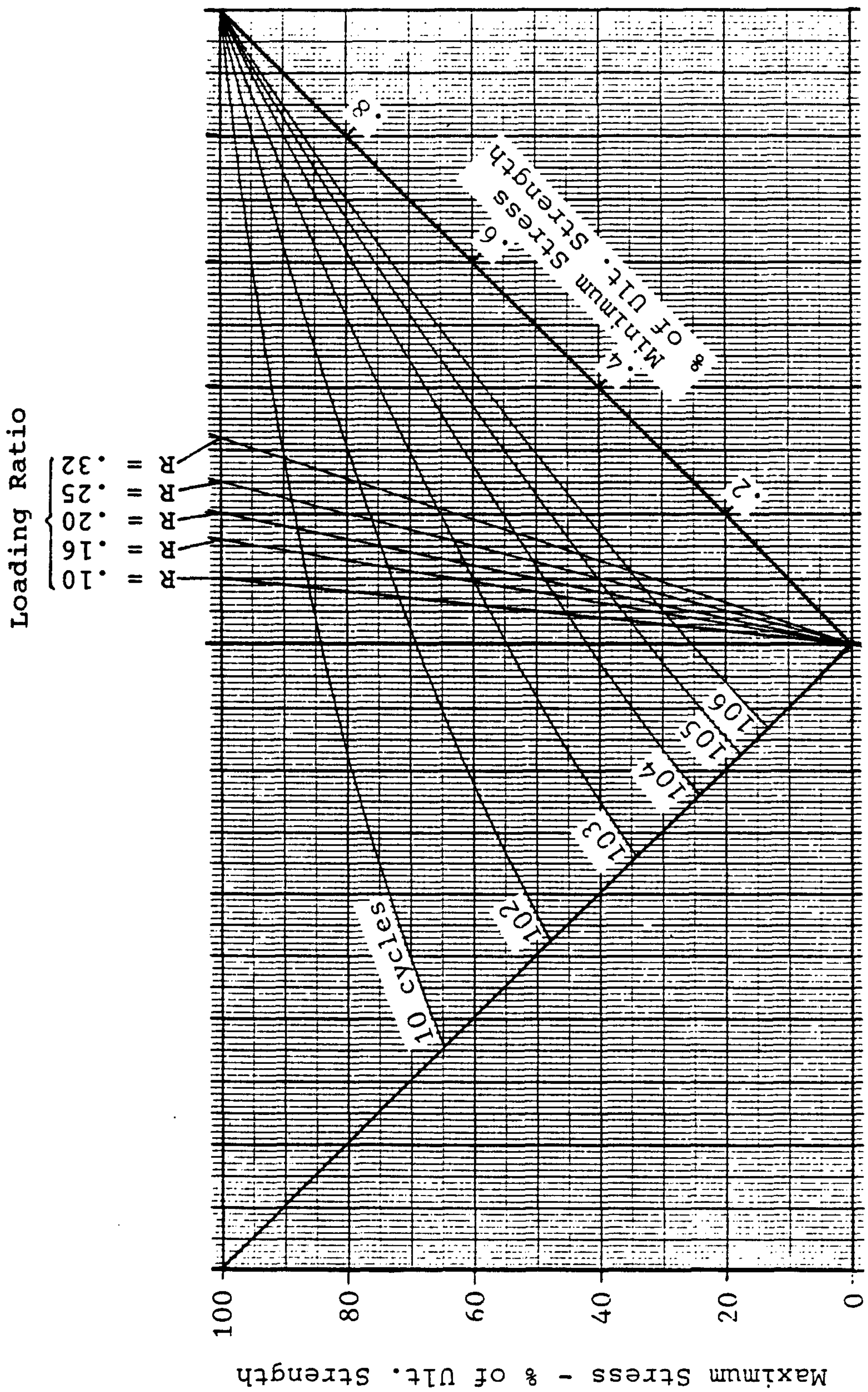


Fig. 3-2. Goodman Diagram for E-Glass Fiber/Epoxy Composite in Bending

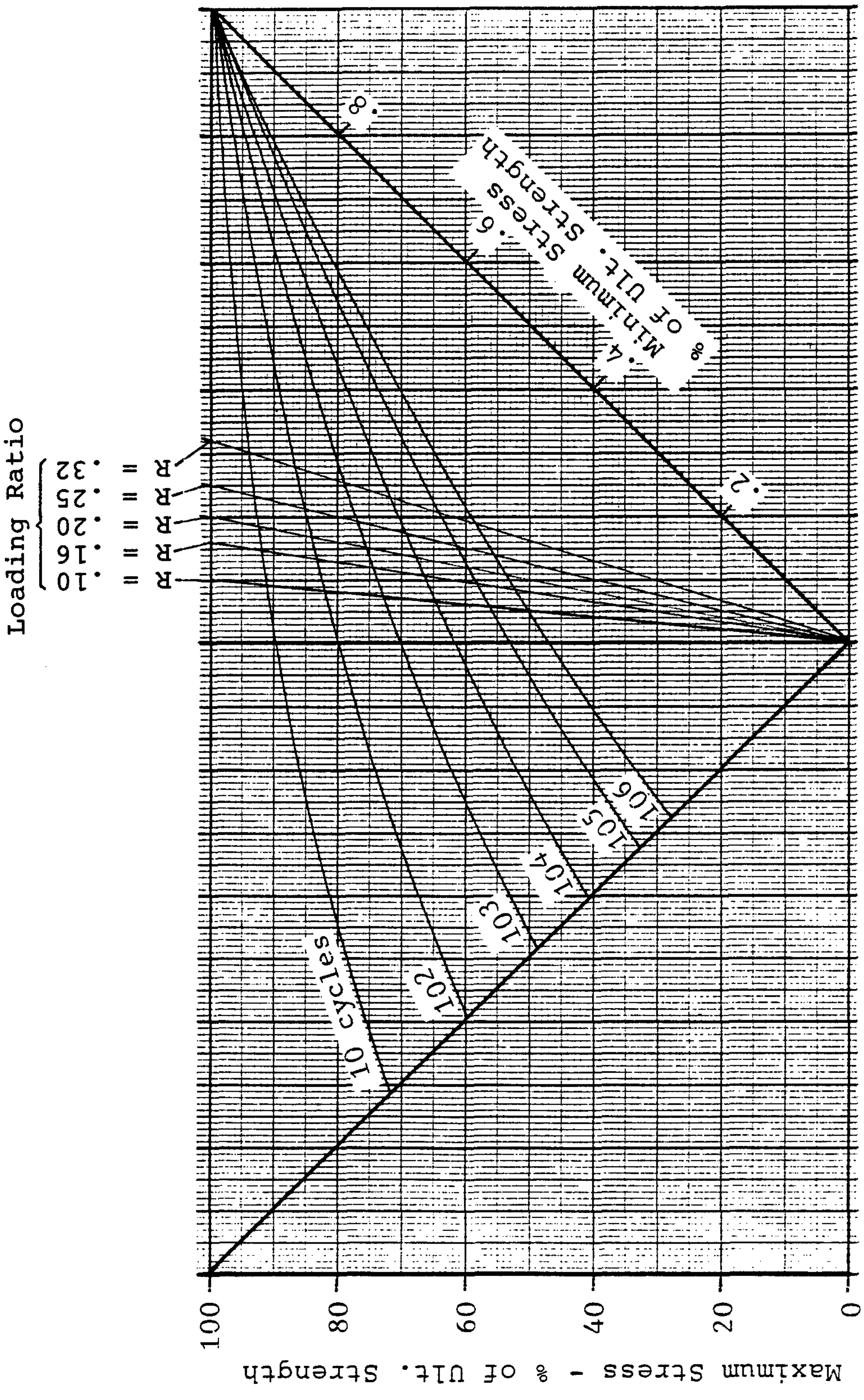


Fig. 3-3 . Goodman Diagram for S2-Glass Fiber/Epoxy Composite in Bending

COMPOSITE PROPERTIES AT R.T.

E-GLASS +/- 5 DEGREES

Flexural Modulus, E = 5.5 x 10E6 psi (37.9 GPa)

Ultimate Flexural Strength, F_u^{fl} = 157,000 psi (1.08 GPa)

Ult. Interlaminar Shear Strength, F_u^s = 8,000 psi (55.2 MPa)

Allowable Bending Stress	Allowable Shear Stress	N, Cycles Loading Ratio, R				
ksi (MPa)	psi (MPa)	.10	.16	.20	.25	.32
105 (724)	5360 (37.0)	230	320	365	510	780
95 (655)	5020 (34.6)	600	880	1100	1540	2400
85 (586)	4400 (30.3)	1850	2800	3500	4800	8000
75 (517)	4240 (29.2)	6200	9000	11.6K	18K	32.5K
65 (448)	3780 (26.1)	22K	36.5K	51K	75K	150K
55 (379)	3450 (23.8)	100K	180K	280K	490K	1000K

Table 3-2. Fatigue Properties of E-Glass For Various Loading Ratios

COMPOSITE PROPERTIES AT R.T.

S2-GLASS +/- 5 DEGREES

Flexural Modulus	E	= 6.5 x 10E6 psi (44.8 GPa)
Ultimate Flexural Strength,	F_u^{fl}	= 185,000 psi (1.28 GPa)
Ult. Interlaminar Shear Strength,	F_u^s	= 11,000 psi (75.8 MPa)

Allowable Bending Stress	Allowable Shear Stress	N, Cycles Loading Ratio, R				
ksi(MPa)	psi(MPa)	.10	.16	.20	.25	.32
146.5(1010)	7370(50.8)	230	285	370	530	940
139.5(962)	6903(47.6)	600	765	1000	1600	3150
131.4(906)	6050(41.7)	1850	2730	4000	6100	12.7K
122.7(846)	5830(40.2)	6200	10.5K	16K	24.2K	54K
114.0(786)	5198(35.8)	22K	38K	56K	92K	282K
103.6(714)	4744(32.7)	100K	233K	418K	900K	2700K

Table 3-3. Fatigue Properties of S2-Glass for Various Loading Ratios

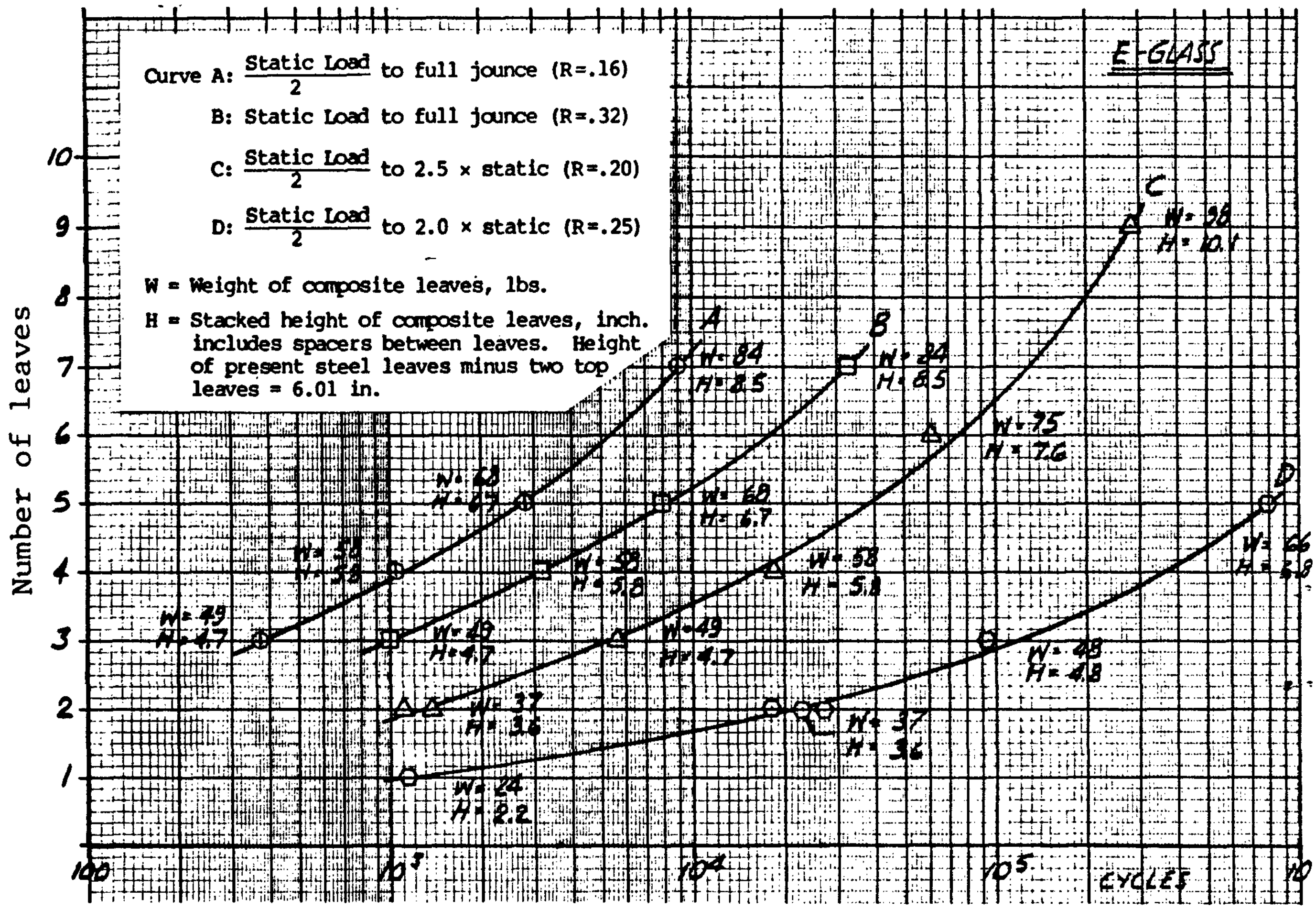


Fig. 3-4 Number of Leaves vs. Fatigue Life Cycles, Rear Spring. (E-Glass; Leaf with Tapered Thickness)

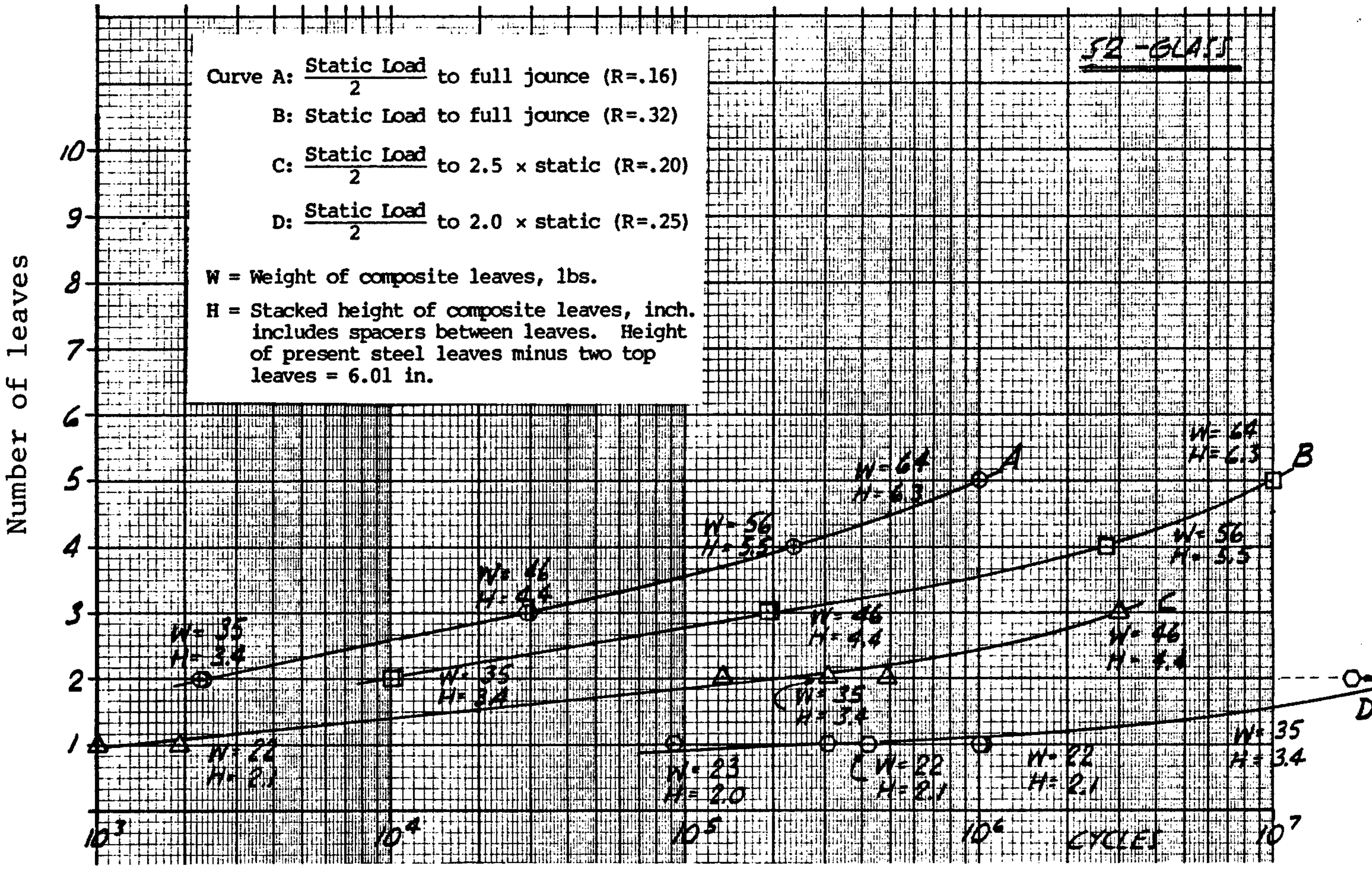


Fig. 3-5. Number of Leaves vs. Fatigue Life Cycles, Rear Spring. (S2-Glass; Leaf with Tapered Thickness)

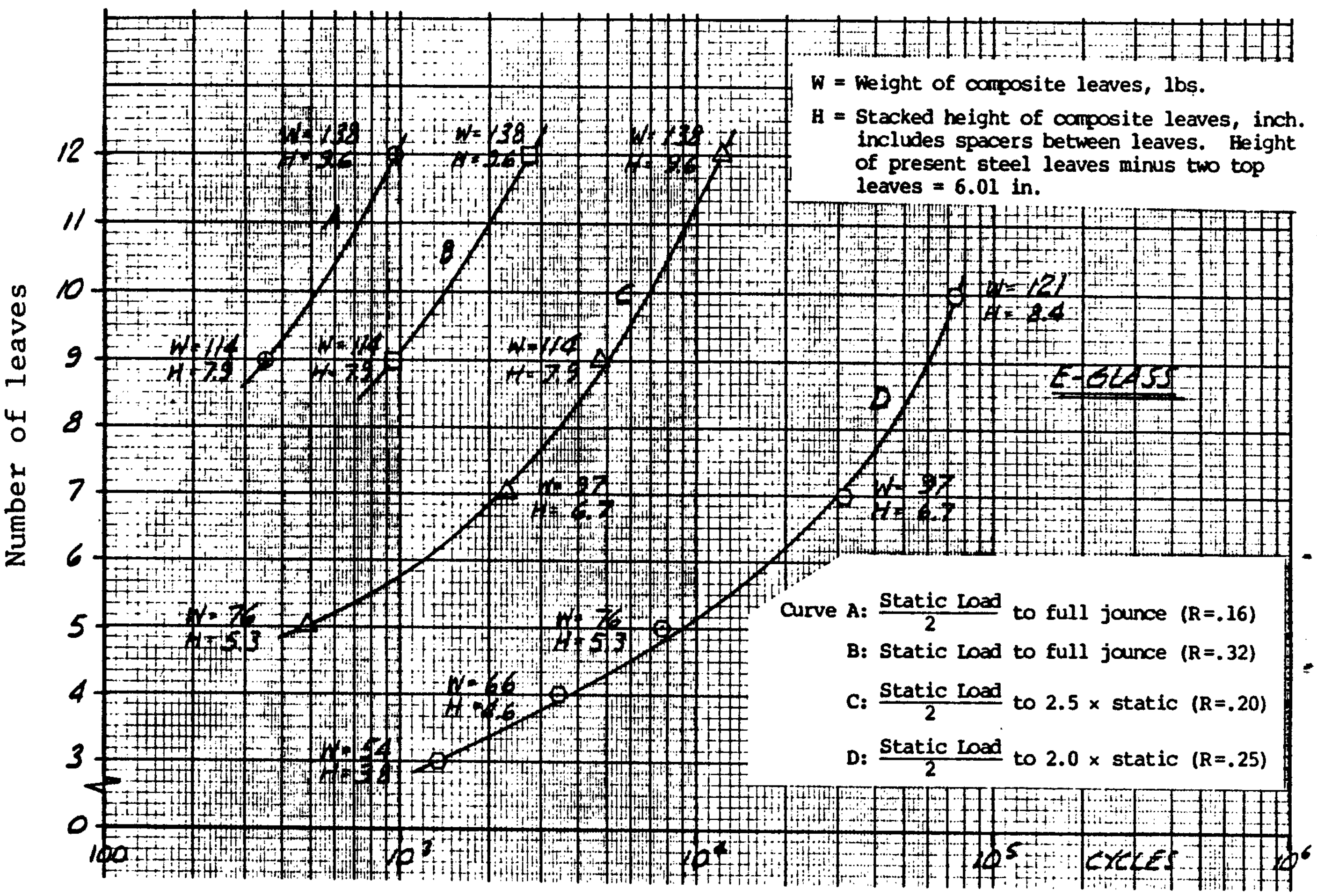


Fig. 3-6. Number of Leaves vs. Fatigue Life Cycles, Rear Spring. (E-Glass; Leaf with Constant Thickness)

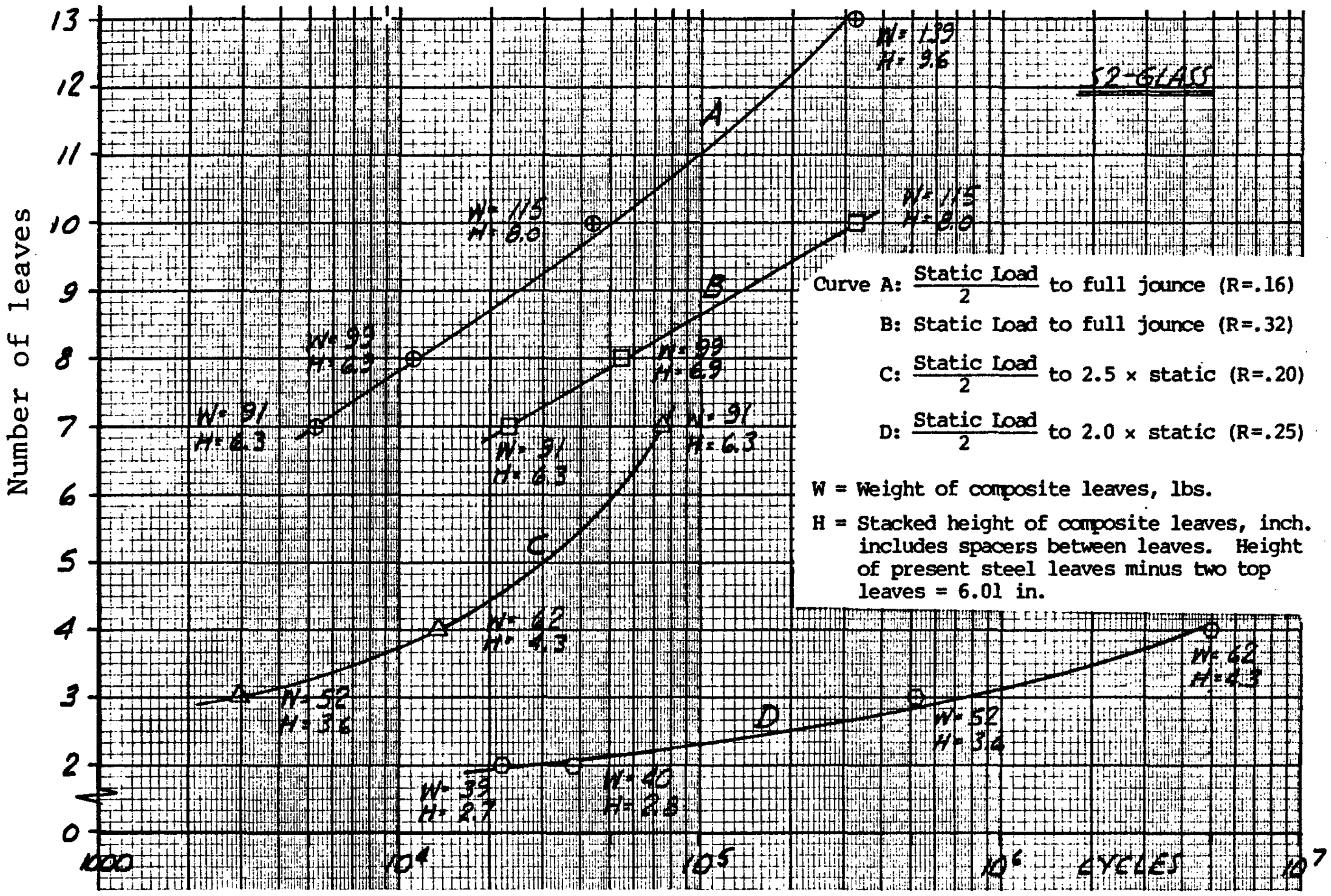


Fig. 3-7. Number of Leaves vs. Fatigue Life Cycles, Rear Spring. (S2-Glass; Leaf with Constant Thickness)

ARMY TRUCK REAR SPRING, DWG. 7409613 (CONTRACT C-1239)

ALL EXCEPT TWO TOP LEAVES ALL S2-GLASS +/-5 DEG.

SOLID LAMINATE SPRING
PARABOLIC TAPER, CONSTANT STRESS

NO. OF LEAVES= 1
SHEAR STRESS CONTROLS, TOO STIFF

NO. OF LEAVES= 2
SPRING CONSTANT= 5059.3 LBS/IN. ALLOW. CONST. STRESS= 108845 PSI

NO. OF LEAVES= 3
SPRING CONSTANT= 4921.66 LBS/IN. ALLOW. CONST. STRESS= 91281.5 PSI

LEAF THICKNESS AS FUNCTION OF X, INCH

FRONT		REAR	
X= .6	H2= .911249	X= .6	H3= .925936
X= 9	H2= .911249	X= 9	H3= .925936
X= 10.2	H2= .944744	X= 10.2	H3= .944744
X= 11.4	H2= .998772	X= 11.4	H3= .998772
X= 12.6	H2= 1.05002	X= 12.6	H3= 1.05002
X= 13.8	H2= 1.09889	X= 13.8	H3= 1.09889
X= 15	H2= 1.14567	X= 15	H3= 1.14567
X= 16.2	H2= 1.19062	X= 16.2	H3= 1.19062
X= 17.4	H2= 1.23392	X= 17.4	H3= 1.23392
X= 18.6	H2= 1.27576	X= 18.6	H3= 1.27576
X= 19.8	H2= 1.31628	X= 19.8	H3= 1.31628
X= 21	H2= 1.35558	X= 21	H3= 1.35558
X= 22.2	H2= 1.39377	X= 22.2	H3= 1.39377
X= 23.4	H2= 1.43094	X= 23.4	H3= 1.43094

AT EDGE OF FIXITY X= 24 IN., SEAT THICKNESS H1= 1.44917 IN.

WEIGHT = 45.7981 LBS.

Fig. 3-8. Typical Computer Printout for Rear Spring.
(S2-Glass; Leaf with Tapered Thickness)

ARMY TRUCK REAR SPRING, DWG. 7409613 (CONTRACT C-1239)

ALL EXCEPT TWO TOP LEAVES S2-GLASS +/-5 DEG.

SOLID LAMINATE
LEAF WITH CONSTANT THICKNESS

ACCEPTABLE SPRING
+++++++++++++++++

NUMBER OF LEAVES = 7
BENDING STRESS = 101429 PSI
SPRING CONSTANT = 4798.82 LBS/INCH
ALLOW. SHEAR STRESS = 4744 PSI
LEAF THICKNESS = .9 INCH
WEIGHT OF 7 LEAVES = 90.72 LBS

Fig. 3-9 Typical Computer Printout for Rear Spring.
(S2-Glass; Leaf with Constant Thickness)

Based on these results, CIBA-GEIGY recommended a design for the rear spring consisting of two steel bottom leaves and three composite leaves of S2-glass fiber/epoxy with tapered thickness. According to Figure 3-5, this design would have a fatigue life of 30,000 cycles at load condition A (half static load to full jounce, R = 0.16), or 3,000,000 cycles at load condition C (1/2 to 2-1/2 times static load, R = 0.20).

TACOM agreed with the recommendation and this design concept was selected for the rear spring.

3.2 Front Spring (Phase II)

It was assumed that the two top leaves, which contain the mounting eyes for attaching the spring to the vehicle, would be made of steel and have a configuration essentially the same as the existing steel spring. The rebound leaf would also remain steel. The remaining leaves would be made from composite materials.

The following design configurations were investigated:

1. E-glass, tapered thickness
2. S2-glass, tapered thickness
3. E-glass, constant thickness
4. S2-glass, constant thickness

Each of these configurations was evaluated for fatigue life when subjected to loading cycles (given in Table 3-4) representative of actual service. The composite front spring assembly must possess the same load/deflection characteristic as the corresponding all-steel spring assembly. The required load/deflection characteristics for the front spring assembly as a whole and the composite leaves alone are presented graphically in Figure 3-10.

Loading Conditions	Load Ratio, R (minimum/maximum load)
A. (Static load/2) to full jounce + max. axle torque	.11
B. Static load to full jounce + max. axle torque	.22
C. (Static load/2) to 2.5 times static load + max. axle torque	.13
D. (Static load/2) to 2.0 times static load + max. axle torque	.15

Notes:

1. Static load for composite leaves: 3451 lbs. (15,350 N)
2. Full jounce: G.V.W. load defl. + 4 in. (102 mm)
3. Load on composite leaves at full jounce: 10,606 lbs (47,175 N)
4. Max. axle torque load on composite leaves: 4608 lbs (20,496 N), added to forward half of the composite leaves and subtracted from aft half.

Table 3-4. Loading Conditions And Ratios For Front Spring Assembly

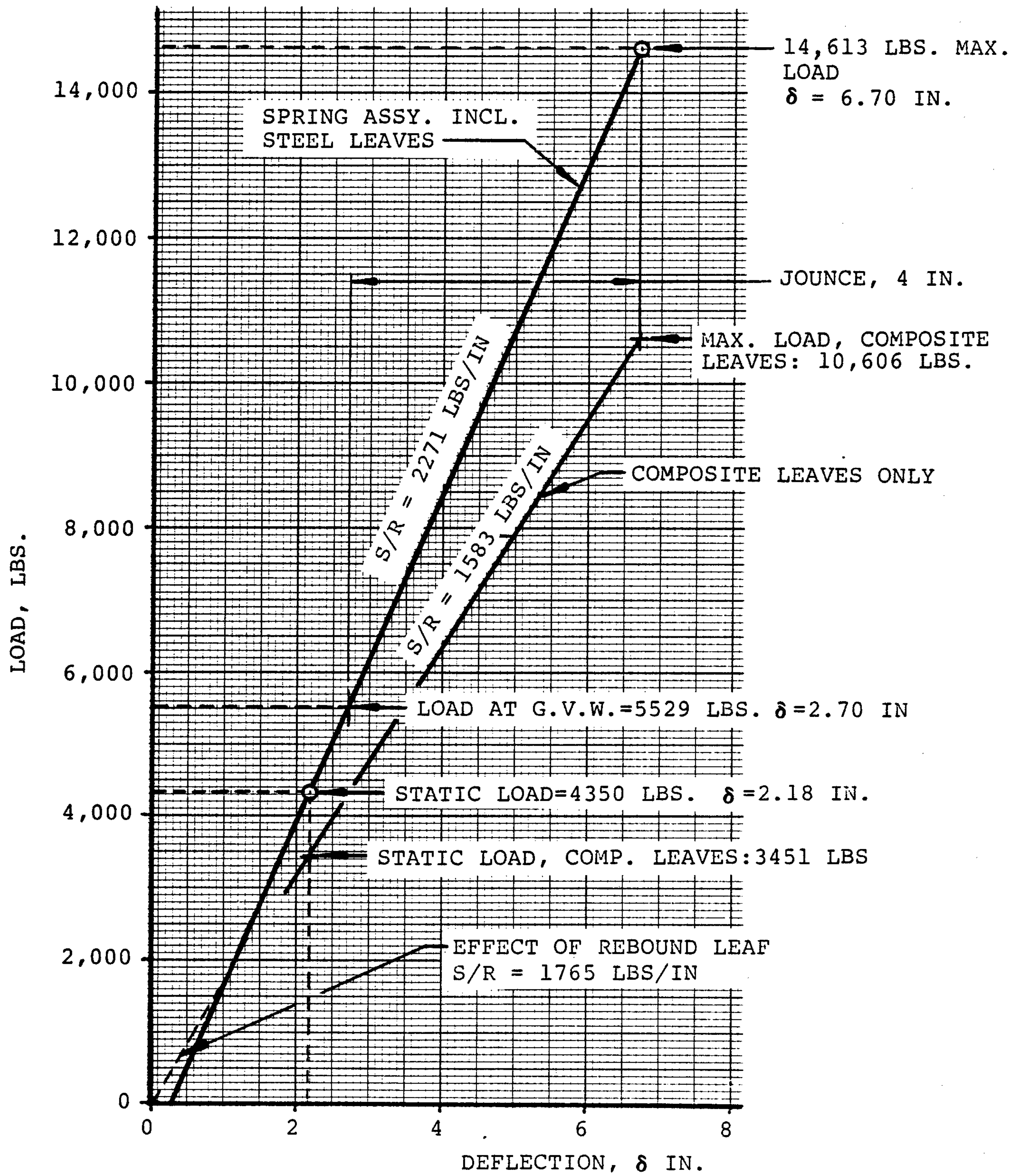


Fig. 3-10 Load Deflection Diagram, Front Spring

The Goodman diagrams for E- and S2- glass/epoxy composites were used to determine fatigue life for various combinations of load ratio and maximum stress. This data is presented in Table 3-5 for E-glass and Table 3-6 for S2-glass.

The CIBA-GEIGY computer program used to calculate the number of leaves required in the rear spring was used again to calculate similar data for the front spring assembly. Figures 3-11 through 3-16 are graphical presentations of the number of leaves as a function of fatigue life for the loading combinations given in Table 3-4. Each figure treats one of four combinations of material type and leaf configuration. The weight and stacked height of the composite leaves were also calculated and are shown on the graphs.

A typical computer printout for leaves with tapered thickness is shown in Figure 3-17, and for constant thickness leaves in Figure 3-18.

The target weight for the composite leaves in the front spring is 25 lb. (11.3 kg), maximum. The stacked height of these leaves should not exceed 4 inches (102 mm) so as to remain within the dimensions of the existing steel spring. From Figures 3-13 through 3-16 and the weight and height constraints, it is apparent that, for a fatigue life of 100,000 cycles, only tapered leaves of S2-glass/epoxy are acceptable. The curves in Figure 3-14 show that a spring assembly with two composite leaves would have an expected fatigue life of 230,000 cycles for load condition B (static load to full jounce plus maximum axle torque, R = 0.22), or 1,450,000 cycles for load condition C (1/2 to 2-1/2 times static load, plus maximum axle torque, R = 0.13). The two composite leaves used in this design solution weigh 21 lb (9.5 kg) and have a stacked height of 2.7 inches (69 mm).

COMPOSITE PROPERTIES AT R.T.

E-GLASS +/- 5 DEGREES

Flexural Modulus, E = 5.5 x 10E6 psi (37.9 GPa)

Ultimate Flexural Strength, F_u^{fl} = 157,000 psi (1.08 GPa)

Ult. Interlaminar Shear Strength, F_u^s = 8,000 psi (55.2 MPa)

Allowable Bending Stress	Allowable Shear Stress	N, Cycles Loading Ratio, R				
ksi(MPa)	psi(MPa)	.10	.11	.13	.15	.22
105(724)	5360(37.0)	230	235	257	283	405
95(655)	5020(34.6)	600	660	737	810	1240
85(586)	4400(30.3)	1850	1920	2220	2470	3900
75(517)	4240(29.2)	6200	6400	7390	8390	14.2K
65(448)	3780(26.1)	22K	23.3K	27.4K	30.8K	57.2K
55(379)	3450(23.8)	100K	105K	128K	146K	318K

Table 3-5. Fatigue Properties of E-Glass For Various Loading Ratios

COMPOSITE PROPERTIES AT R.T.

S2-GLASS +/- 5 DEGREES

Flexural Modulus,	E_{fl}	= 6.5 x 10E6 psi (44.8 GPa)
Ultimate Flexural Strength,	F_u	= 185,000 psi (1.28 GPa)
Ult. Interlaminar Shear Strength,	F_u^s	= 10,000 psi (75.8 MPa)

Allowable Bending Stress	Allowable Shear Stress	N, Cycles Loading, Ratio, R				
ksi(MPa)	psi(MPa)	.10	.11	.13	.15	.22
146.5(1010)	7370(50.8)	230	235	243	272	420
139.5(962)	6903(47.6)	600	605	640	739	1225
131.4(906)	6050(41.7)	1850	1860	2120	2530	4490
122.7(846)	5830(40.2)	6200	6800	8200	9500	17.5K
114.0(786)	5198(35.8)	22K	25.1K	30.2K	35.2K	66K
103.6(714)	4744(32.7)	100K	117K	155K	196K	530K

Table 3-6. Fatigue Properties of S2-Glass For Various Loading Ratios

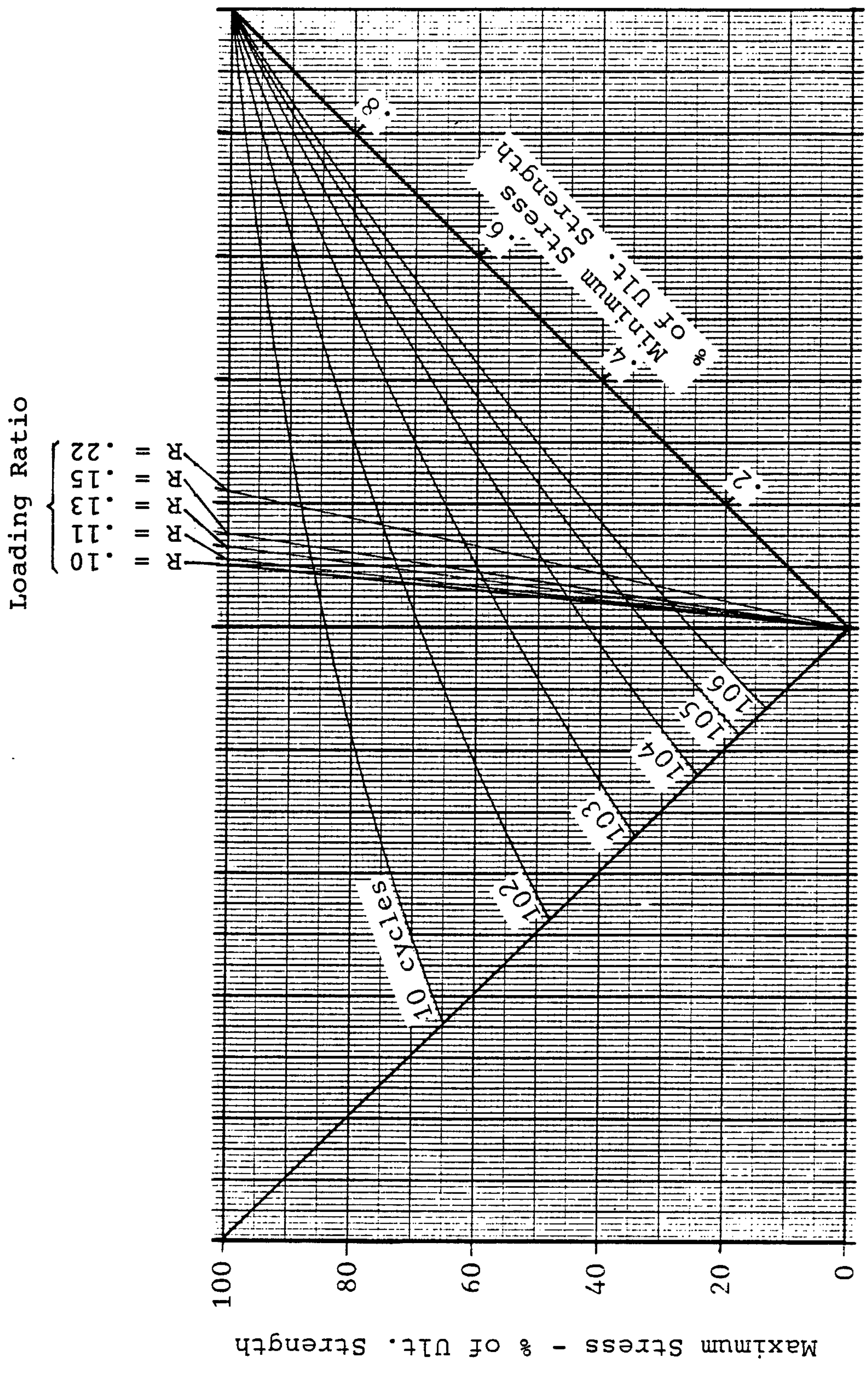


Fig. 3-11. Goodman Diagram for E-Glass Fiber/Epoxy Composite in Bending

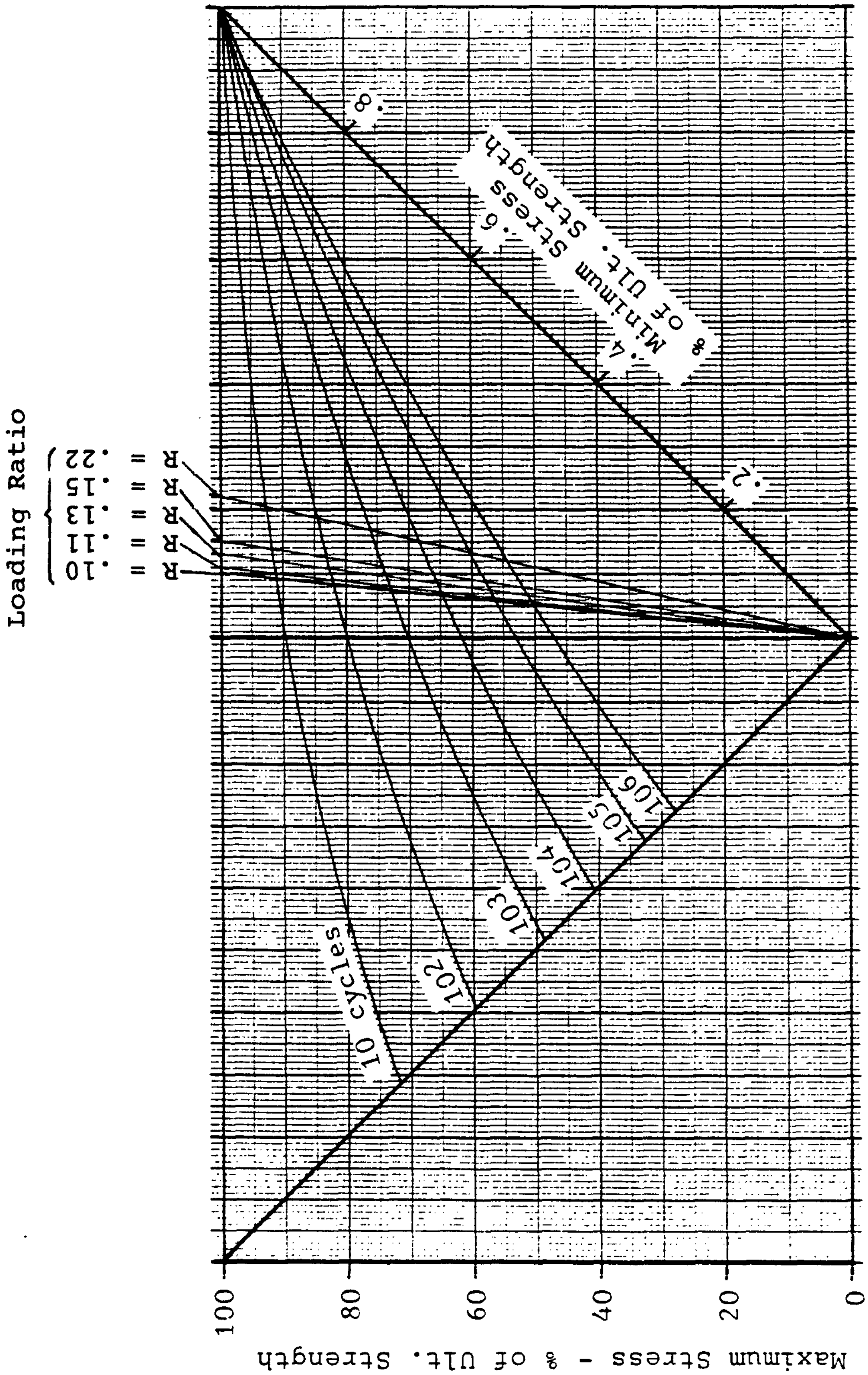


Fig. 3-12. Goodman Diagram for S2-Glass Fiber/Epoxy Composite in Bending

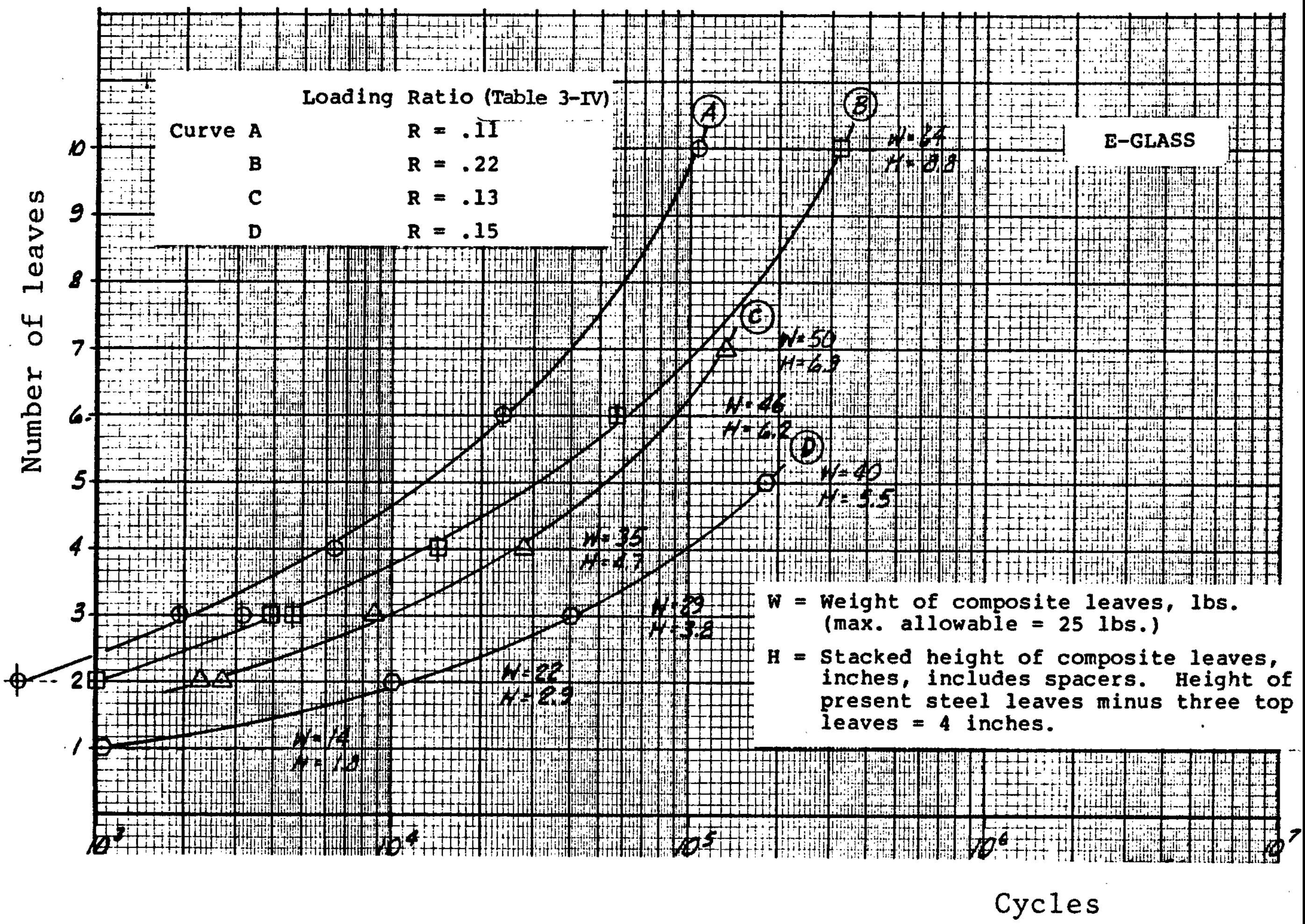


Fig. 3-13. Number of Leaves vs. Fatigue Life Cycles, Front Spring. (E-Glass; Leaf with Tapered Thickness)

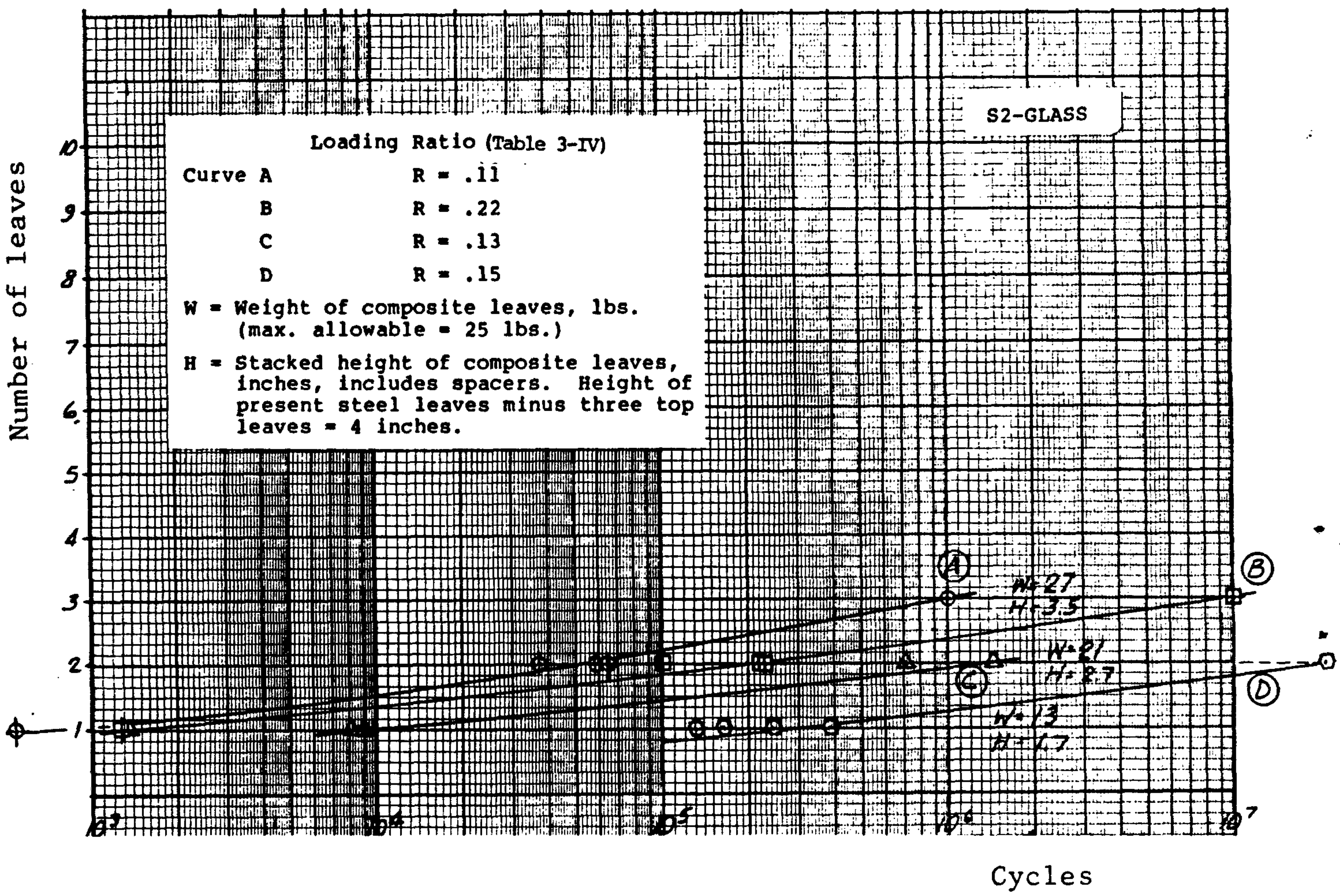


Fig. 3-14. Number of Leaves vs. Fatigue Life Cycles, Front Spring. (S2-Glass; Leaf with Tapered Thickness)

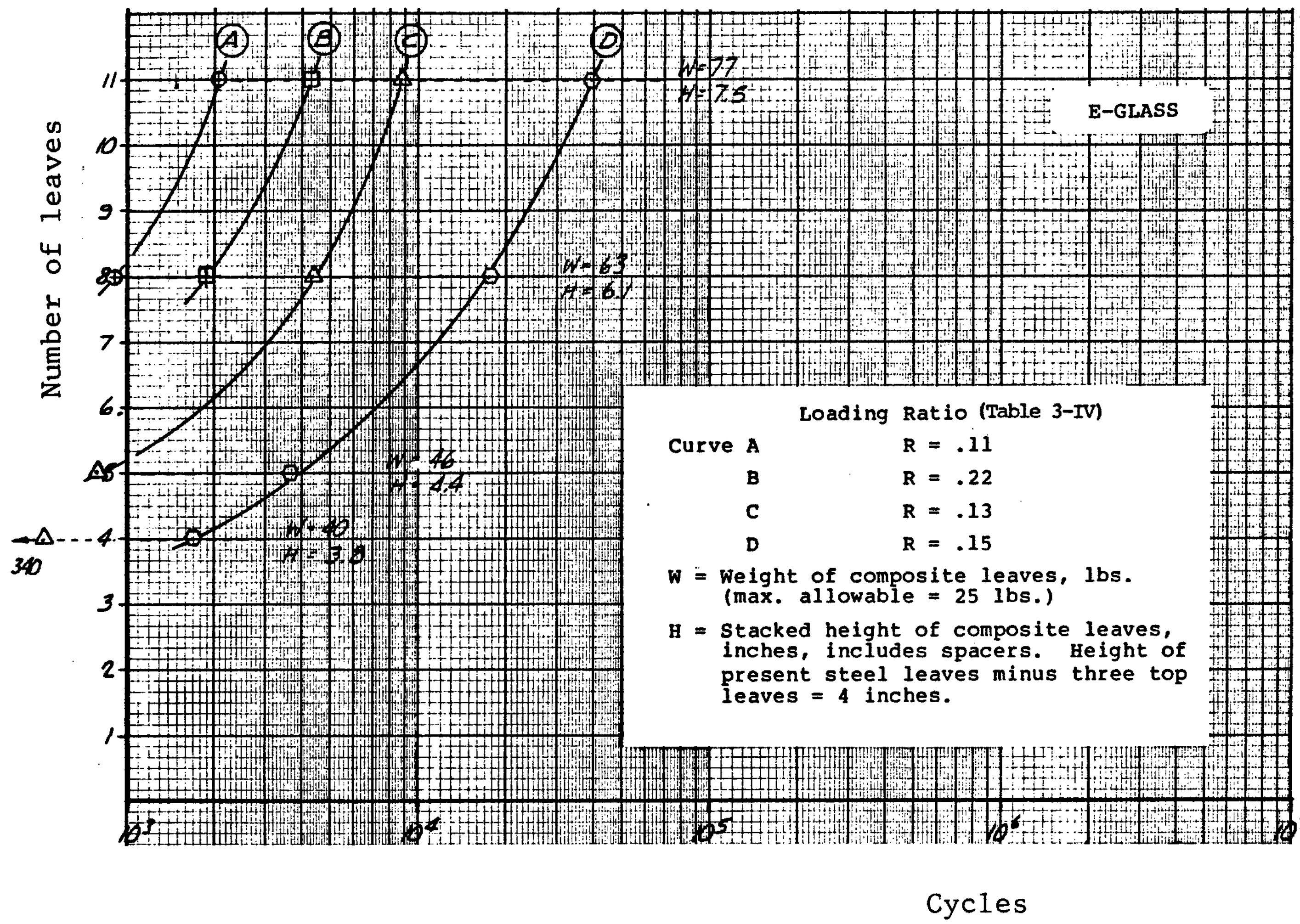


Fig. 3-15 Number of Leaves vs. Fatigue Life Cycles, Front Spring.
(E-Glass; Leaf with Constant Thickness)

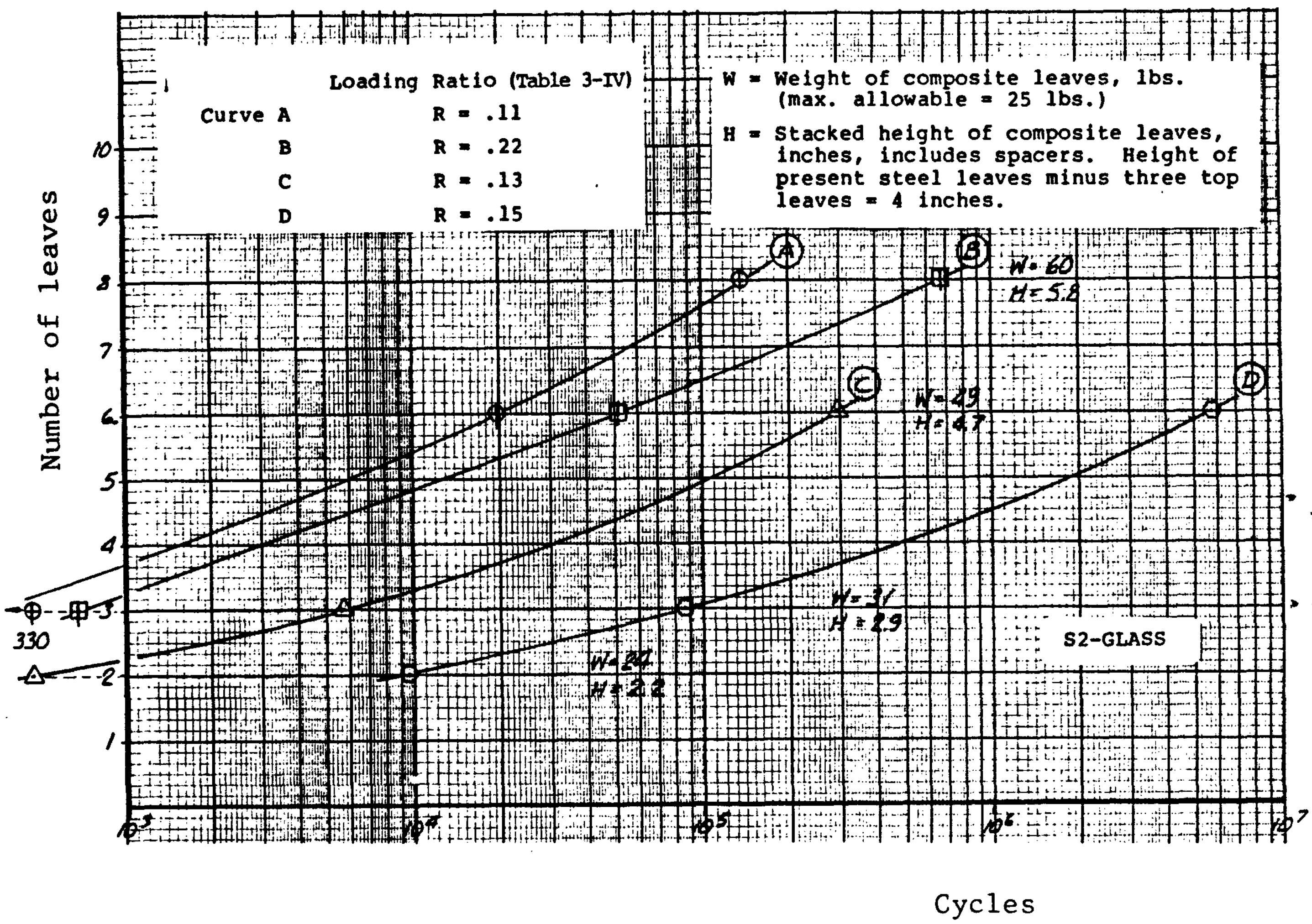


Fig. 3-16 Number of Leaves vs. Fatigue Life Cycles, Front Spring (S2-Glass; Leaf with Constant Thickness)

ARMY TRUCK FRONT SPRING, DWG. 7411110 (CONTRACT C-1239, PHASE II)

NO. 1, 2 AND REBOUND LEAVES STEEL
OTHER LEAVES S2-GLASS +/-5 DEG./EPOXY

SOLID LAMINATE SPRING
PARABOLIC TAPER, CONSTANT STRESS

NO. OF LEAVES= 1
SPRING CONSTANT= 1619.53 LBS/IN. ALLOW. CONST. STRESS= 126227 PSI

NO. OF LEAVES= 2
SPRING CONSTANT= 1548.91 LBS/IN. ALLOW. CONST. STRESS= 96022.6 PSI

LEAF THICKNESS AS FUNCTION OF X, INCH

FRONT		REAR	
X= .625	H2= .732765	X= .625	H3= .743504
X= 6.875	H2= .732765	X= 6.875	H3= .743504
X= 8.125	H2= .748322	X= 8.125	H3= .748322
X= 9.375	H2= .803826	X= 9.375	H3= .803826
X= 10.625	H2= .855739	X= 10.625	H3= .855739
X= 11.875	H2= .904677	X= 11.875	H3= .904677
X= 13.125	H2= .9511	X= 13.125	H3= .9511
X= 14.375	H2= .995361	X= 14.375	H3= .995361
X= 15.625	H2= 1.03774	X= 15.625	H3= 1.03774
X= 16.875	H2= 1.07845	X= 16.875	H3= 1.07845
X= 18.125	H2= 1.11768	X= 18.125	H3= 1.11768
X= 19.375	H2= 1.15557	X= 19.375	H3= 1.15557
X= 20.625	H2= 1.19227	X= 20.625	H3= 1.19227
X= 21.875	H2= 1.22787	X= 21.875	H3= 1.22787
X= 23.125	H2= 1.26246	X= 23.125	H3= 1.26246
X= 24.375	H2= 1.29613	X= 24.375	H3= 1.29613

AT EDGE OF FIXITY X= 25 IN., SEAT THICKNESS H1= 1.31264 IN.

WEIGHT = 20.8663 LBS.

Fig. 3-17. Typical Computer Printout for Front Spring.
(S2-Glass; Leaf with Tapered Thickness)

ARMY TRUCK FRONT SPRING, DWG. 7411110 (CONTRACT C-1239 PHASE II)

NO. 1,2 AND REBOUND LEAVES STEEL
OTHER LEAVES S2-GLASS +/-5 DEG./EPOXY

SOLID LAMINATE
LEAF WITH CONSTANT THICKNESS

ACCEPTABLE SPRING
++++++++++++++++

NUMBER OF LEAVES = 6
BENDING STRESS = 100712 PSI
SPRING CONSTANT = 1517.16 LBS/INCH
ALLOW. SHEAR STRESS = 4744 PSI
LEAF THICKNESS = .74 INCH
WEIGHT OF 6 LEAVES = 48.618 LBS

Fig. 3-18. Typical Computer Printout for Front Spring.
(S2-Glass; Leaf with Constant Thickness)

Based on these results, CIBA-GEIGY recommended a design for the front spring consisting of two steel leaves with mounting eyes, steel rebound leaf and two composite leaves of S2-glass fiber/epoxy with tapered thickness. TACOM agreed with this recommendation and this design concept was selected for the front spring.

4. Composite Material Properties

The fatigue load study, presented in the previous section (Section 3), showed that S2-glass fiber/epoxy would be required for the composite leaves in both the rear spring (Phase I) and the front spring (Phase II). Two resin systems were selected for evaluation, CIBA-GEIGY Systems R7269-S2 and R9269-S2. Preimpregnation of the S2-glass fiber was performed in-house. The S2-glass fiber was supplied by Owens Corning Fiberglass.

Flexural and interlaminar shear properties were obtained from specimens with 0 degrees and +/- 5 degrees fiber orientation. Specimens cured at 50 psi and 100 psi were tested. All tests were performed at room temperature.

Flexural tests were performed per ASTM D790 with a 32:1 span to depth ratio. Shear tests were performed per ASTM D2344.

The results of the material properties testing program for the two systems are presented in Tables 4-1 through 4-6.

The material properties for the two resin systems are very similar, with R7269-S2 showing slightly higher values and less scatter. The curing pressure had a significant effect on the properties. This is because a net resin content was used for the prepreg, requiring higher pressure for the laminate to consolidate. A net resin content was desireable because it simplifies fabrication of the leaves in that cleaning of the molds is less time consuming than with excess resin.

Based on the test results, it was decided to use the R7269-S2 system and 100 psi curing pressure for both front and rear springs. Later in the program, after testing individual leaves, the +/- 5 degrees fiber orientation was abandoned in favor of 0 degrees orientation.

TABLE 4-1. Material Properties for R7269-S2

Fiber Direction: +/- 5 degrees
Curing Pressure: 50 psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi(MPa)	Flex. Mod. msi(GPa)
1	.750(19.05)	.136(3.45)	746(3318)	174(1200)	8.01(55.2)
2	.750(19.05)	.136(3.45)	725(3225)	170(1172)	7.69(53.0)
3	.750(19.05)	.135(3.43)	636(2829)	151(1041)	7.52(51.8)
4	.750(19.05)	.134(3.40)	680(3025)	164(1131)	7.69(53.0)
5	.750(19.05)	.135(3.43)	660(2936)	157(1083)	7.69(53.0)
			Average	163(1124)	7.66(52.8)

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi(MPa)
1	.511(12.98)	.501(12.73)	2790(12,411)	8173(56.4)
2	.524(13.31)	.502(12.75)	2325(10,342)	6629(45.7)
3	.511(12.97)	.502(12.75)	2640(11,743)	7719(53.2)
4	.510(12.95)	.500(12.70)	2825(12.566)	8309(57.3)
5	.511(12.98)	.502(12.75)	2675(11,899)	7821(53.9)
			Average	7730(53.3)

TABLE 4-2. Material Properties For R7269-S2

Fiber Direction: 0 degrees
Curing Pressure: 50 psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi(MPa)	Flex. Mod.
1	.748(19.00)	.162(4.12)	817(3634)	216(1489)	
2	.750(19.05)	.162(4.12)	673(2994)	178(1227)	
3	.747(18.97)	.160(4.06)	813(3616)	221(1524)	
4	.751(19.08)	.161(4.09)	825(3670)	220(1517)	
5	.752(19.10)	.162(4.12)	826(3674)	218(1503)	
			Average	211(1455)	

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi(MPa)
1	.498(12.65)	.318(8.08)	2221(9880)	10,518(72.5)
2	.500(12.70)	.315(8.00)	2203(9799)	10,490(72.3)
3	.500(12.70)	.315(8.00)	2229(9915)	10,614(73.2)
4	.498(12.65)	.314(7.98)	2192(9751)	10,513(72.5)
5	.500(12.70)	.309(7.85)	2170(9653)	10,534(72.6)
			Average	10,534(72.6)

TABLE 4-3. Material Properties for R7269-S2

Fiber Direction: 0 degrees
Curing Pressure: 100 psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi(MPa)	Flex. Mod. msi(GPa)
1	.741(18.82)	.148(3.76)	834(3710)	183(1262)	7.88(54.3)
2	.742(18.85)	.147(3.73)	809(3599)	180(1241)	8.50(58.6)
3	.740(18.80)	.150(3.81)	842(3745)	180(1241)	8.69(59.9)
			Average	181(1248)	8.36(57.6)

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi(MPa)
1	.252(6.40)	.145(3.68)	534(2375)	10,961(75.6)
2	.252(6.40)	.145(3.68)	587(2611)	12,048(83.1)
3	.252(6.40)	.145(3.68)	585(2602)	12,007(82.8)
			Average	11,672(80.5)

TABLE 4-4. Material Properties for R9269-S2

Fiber Direction: +/- 5 degrees

Curing Pressure: 50 psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Specimen Dimensions Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi(MPa)	Flex. Mod. msi(GPa)
1	.751(19.08)	.134(3.40)	753(3350)	179(1234)	7.89(54.4)
2	.752(19.10)	.133(3.38)	702(3123)	169(1165)	8.06(55.6)
3	.751(19.08)	.134(3.40)	750(3336)	178(1227)	7.89(54.4)
			Average	175(1207)	7.76(53.5)

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Specimen Dimensions Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi(MPa)
1	.515(13.08)	.499(12.68)	2425(10,787)	7,077(48.8)
2	.512(13.01)	.503(12.78)	2600(11,565)	7,572(52.2)
3	.510(12.95)	.503(12.78)	2060(9,163)	6,023(41.5)
4	.512(13.01)	.503(12.78)	2400(10,676)	6,989(48.2)
5	.511(12.98)	.502(12.75)	2255(10,031)	6,593(45.5)
			Average	6,851(47.2)

TABLE 4-5. Material Properties for R9269-S2

Fiber Direction: Ø degrees
Curing Pressure: 5Ø psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi(MPa)	Flex. Mod.
1	.741(18.82)	.152(3.86)	691(3Ø74)	21Ø(1448)	
2	.748(19.ØØ)	.154(3.91)	758(3372)	222(1531)	
3	.746(18.95)	.15Ø(3.81)	618(2749)	191(1317)	
4	.745(18.92)	.157(3.99)	735(3269)	2Ø8(1434)	
5	.744(18.9Ø)	.155(3.94)	744(331Ø)	216(1489)	
			Average	2Ø9(1441)	

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi(MPa)
1	.496(12.6Ø)	.5Ø9(12.93)	3Ø76(13,683)	9,138(63.Ø)
2	.498(12.65)	.5Ø5(12.83)	3133(13,936)	9,343(64.4)
3	.497(12.62)	.5Ø8(12.9Ø)	3115(13,856)	9,253(63.8)
4	.498(12.65)	.5Ø7(12.88)	31Ø9(13,83Ø)	9,235(63.7)
5	.486(12.34)	.5Ø8(12.9Ø)	3136(13,95Ø)	9,335(64.4)
			Average	9,261(63.9)

TABLE 4-6 Material Properties for R9269-S2

Fiber Direction: Ø degrees
Curing Pressure: 1ØØ psi

FLEXURAL STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	Flex. Str. ksi (MPa)	Flex. Mod. msi (GPa)
1	.746(18.95)	.145(3.68)	8Ø3(3572)	179(1234)	7.94(54.7)
2	.747(18.97)	.148(3.76)	811(36Ø8)	174(12ØØ)	7.46(51.4)
3	.747(18.97)	.145(3.68)	813(3616)	181(1248)	8.4Ø(57.9)
			Average	178(1227)	7.93(54.7)

INTERLAMINAR SHEAR STRENGTH

Specimen No.	Specimen Dimensions Width In (mm)	Thickness In (mm)	Load Lbs (N)	I.L.S. Strength psi (MPa)
1	.253(6.43)	.144(3.66)	569(2531)	11,714(8Ø.8)
2	.252(6.4Ø)	.144(3.66)	535(238Ø)	11,Ø57(76.2)
3	.251(6.38)	.143(3.63)	546(2429)	11,4Ø9(78.7)
			Average	11,393(78.6)

5. Design Studies

5.1 Introduction

The objective of this program was to develop a manufacturing process by which lightweight composite leaf springs for a 5-ton truck could be produced in quantity. An existing composite spring design, developed under an earlier contract, was to be used for the manufacturing study. Reconfiguration of the existing design was to be limited to that necessary to the development of the manufacturing process. However, as mentioned earlier, the Army had increased load and deflection requirements significantly, necessitating an entirely new design. The new spring design was selected based on the results of the fatigue load study described in Section 3.

Two spring assemblies were involved in the program, which was divided into two phases. Phase I involved the rear spring assembly, Ordnance Part no. 7409613, while Phase II involved the front spring assembly, Ordnance Part no. 7411110.

5.2 Design Criteria

Design criteria for the composite leaf spring are structural integrity, interchangeability with the present metal springs, lighter weight than the metal springs, cost, and, most important, compatibility with current manufacturing technology to allow quantity production (25 sets of springs per day).

Other requirements for the spring assemblies are as follows:

5.2.1 Rear Spring Assembly

- The rate of spring deflection for an unclamped spring assembly shall be 5983 +/- 618 lbs per inch (1048 +/- 108 N/mm) and the deflection at a load of 12,680 lbs (56,404 N) shall be 2.125 +/- .125 inches, (54 +/- 3 mm) from the free state.
- The operating temperature range shall be -65 to +250 degrees F (-56 to 121 degrees C).
- The weight of the spring assembly shall be 175 lbs (79 kg) or less. Current steel spring weight is 293 lbs (133 kg).

- The maximum vertical load on the spring assembly shall be 56,060 lbs (249,367 N). This is the sum of the static load, 12,680 lbs (56,403 N), and 7.25 inches (184 mm) jounce.

- The composite leaves shall be designed for a fatigue life as described in the fatigue load study presented in Section 3.

5.2.2 Front Spring Assembly

- The rate of spring deflection for an unclamped spring assembly shall be 2271 +/- 135 lbs per inch (398 +/- 24 N/mm.)

- The operating temperature range shall be -65 to +250 degrees F (-54 to 121 degrees C).

- The weight of the spring assembly shall be 90 lbs (41 kg) or less. Current steel spring weight is 149 lbs (68 kg).

- The maximum vertical load on the spring assembly shall be 14,613 lbs (64,999N). This is the sum of the load at gross vehicle weight (GVW) 5,529 lbs (24,593 N), and 4.0 inches (102 mm) jounce.

- The maximum axle torque of 165,270 in-lbs (18,673 Nm) shall be reacted by the spring assembly.

- The composite leaves shall be designed for a fatigue life as described in the fatigue load study presented in Section 3.

5.3 Design - Phase I, Rear Spring Assembly

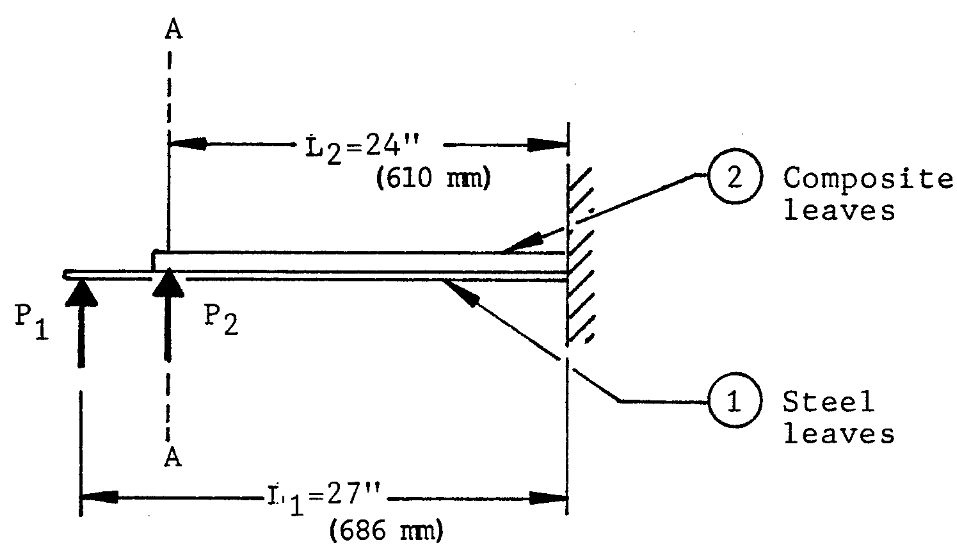
The dimensions of the present steel spring assembly are given on TACOM Drawing no. 7409613. The distance between the center and the end support point is 27 inches (686 mm) with the spring in the flat, unloaded condition. The spring is symmetrical about its center line. The width and thickness of the steel leaf are 4 inches (102 mm) and .558 inches (14 mm), respectively.

The two long leaves (bottom leaves) in the steel spring assembly are used in the composite spring because of interchangeability requirements. The steel leaves provide contact points to the vehicle and fit into the existing support brackets. Composite materials have much lower shear strength than steel, and a composite leaf or leaves would have to be much thicker at the tip than the steel leaves in order to take the vertical shear loads, and thus would not fit the existing support bracket on the vehicle. The maximum length for the composite leaves that can be allowed without interference with the brackets is 49 inches (1245 mm). Because of the shear characteristics, all composite leaves were designed to have equal length.

The material and configuration of the composite leaves were selected from the results of the fatigue load study. S2-glass fiber/epoxy and a leaf with tapered thickness was selected as the combination that would best satisfy both fatigue life requirements and geometric constraints.

5.3.1 Spring Deflection Rate

Calculating the required spring rate for the composite leaves is somewhat complicated because of the different lengths of the steel and composite leaves. It is an iterative process in that the stiffness factor (EI) must be estimated for the composite leaves.



Stiffness factors

Steel	(EI)	=	3.48 x 10ØE6	psi (24 GPa)
Composite	(EI)	=	12.1 x 10ØE6	psi (83 GPa)

Deflection of steel leaves at sect. A-A

$$\delta_1 = \frac{P_1 L_2^{2}(3L_1 - L_2)}{6(EI)_1} - \frac{P_2 L_2^3}{3(EI)_1}$$

Deflection of composite leaves at sect. A-A

$$\delta_2 = \frac{P_2 L_2^{3}}{3(EI)_2}$$

$\delta_1 = \delta_2$ when steel and composite leaves are in contact.

$$\frac{P_1 L_2^{2}(3L_1 - L_2)}{6(EI)_1} - \frac{P_2 L_2^{3}}{3(EI)_1} = \frac{P_2 L_2^{3}}{3(EI)_2}$$

$$P_1 \quad \frac{L_2^{2}(3L_1 - L_2)}{6(EI)_1} = \frac{P_2 L_2^{3}}{3}\left(\frac{(EI)_1 + (EI)_2}{(EI)_1 (EI)_2}\right)$$

$$\therefore \qquad P_2 = P_1 \frac{3L_1 - L_2}{2L_2} \frac{(EI)_2}{(EI)_1 + (EI)_2}$$

substitute L_1, L_2, $(EI)_1$, $(EI)_2$

$$P_2 = .92\ P_1$$

The deflection for the composite leaves is then,

$$\delta = \frac{.92\,P_1 L_2{}^3}{3(EI)_2}$$

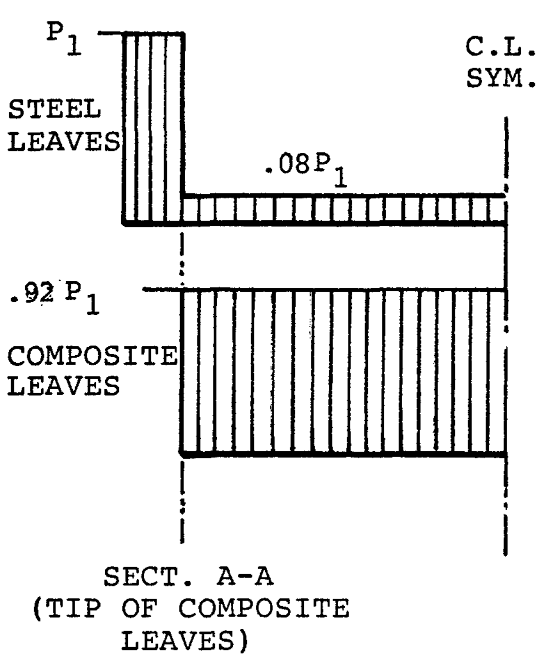
$$\delta = .000351\ P_1$$

and the spring rate, $P_1/\delta = \dfrac{1}{.000351} = 2846$ lbs/in per half or 5692 lbs/in (997 N/mm)

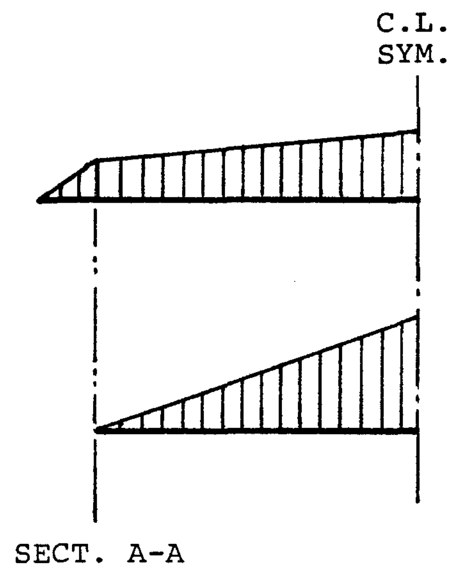
This is not an exact number since an average value of EI was used for the tapered composite leaves.

A load/deflection diagram for the rear spring assembly is shown in Figure 5-1.

Shear and moment diagrams show that there is no severe stress concentration in the steel leaves at section A-A as may be expected.



SHEAR DIAGRAM



MOMENT DIAGRAM

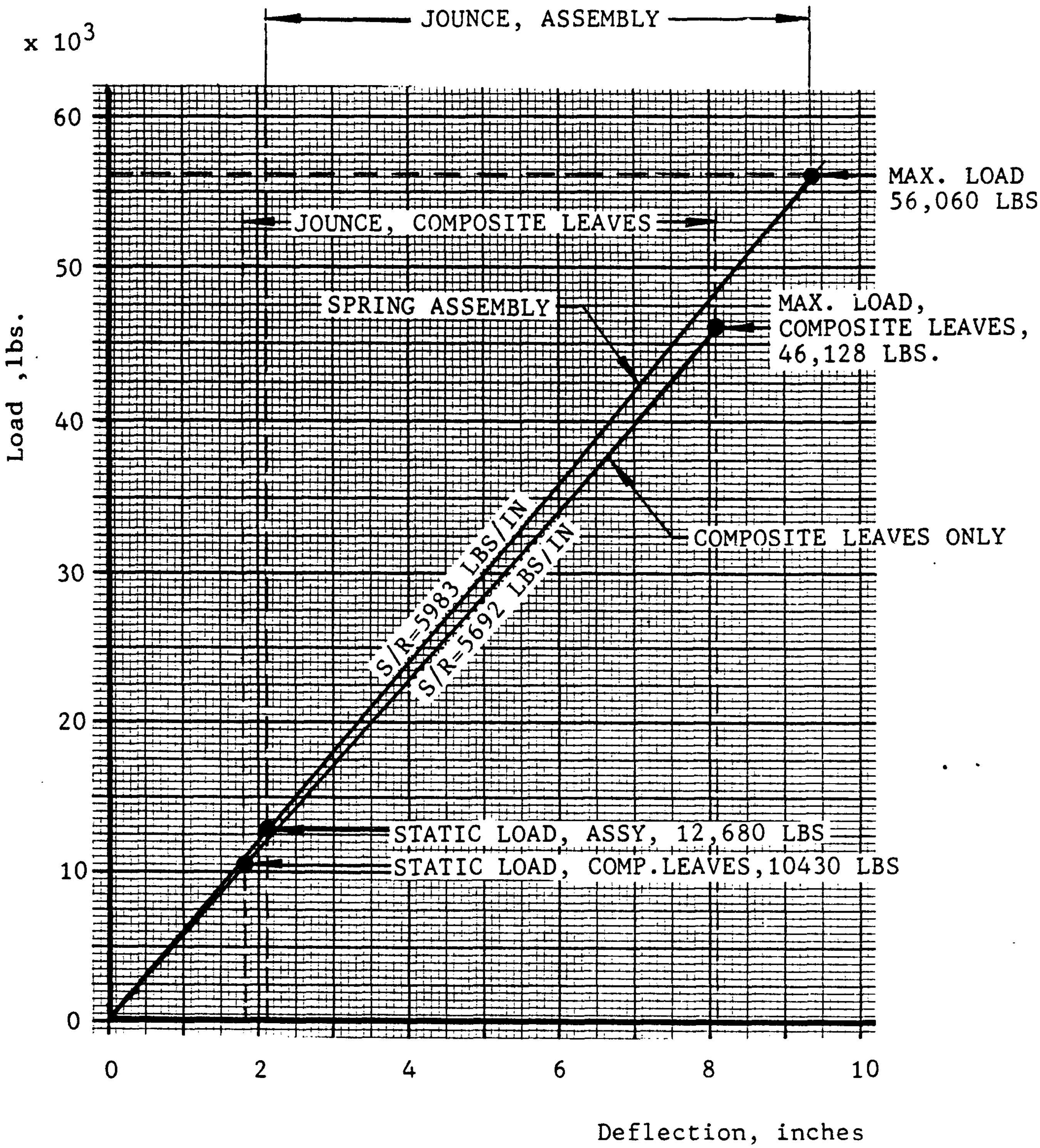


Fig. 5-1 Load/Deflection Diagram for Rear Spring

5.3.2 Computer Analysis

A number of composite programs have been developed by CIBA-GEIGY to analyze and optimize leave spring designs for trucks and automobiles. The programs accept as input the geometric restraints (such as length and width), load and stiffness requirements, and material properties. The output of the program is a spring design that meets load (static and fatigue), stiffness, and deflection requirements with minimum weight and number of leaves.

The CIBA-GEIGY computer programs cover leaves with constant thickness, linear - or parabolic-tapered thickness, tapered leaf width, and sandwich type leaves consisting of different materials. Several of these programs were used to establish the data in Section 3.

For the rear spring composite leaves, parabolic tapering of the leaf thickness was selected as the best suitable design. This tapering is based on a computer analysis which optimizes with a constant bending stress along the length of the leaf. Near the end, away from the seat, shear stresses (rather than bending stresses) are critical and, therefore, the thickness becomes constant. The program output is shown in Figure 5-2.

The leaf thickness is calculated for 2Ø points between the center of the leaf and the tip, but any number of points may be requested. For instance, N/C machining of tooling surfaces requires thickness dimensions at length increments of .1Ø inch (2.5 mm) or less. The program output shows a thickness distribution which is identical for all leaves.

The program output also shows calculated spring rate, bending stress and combined weight of all leaves.

ARMY TRUCK REAR SPRING, DWG. 7409613 (CONTRACT C-1239)

ALL EXCEPT TWO TOP LEAVES ALL S2-GLASS +/-5 DEG.

SOLID LAMINATE SPRING
PARABOLIC TAPER, CONSTANT STRESS

NO. OF LEAVES= 1
SHEAR STRESS CONTROLS, TOO STIFF

NO. OF LEAVES= 2
SPRING CONSTANT= 5059.3 LBS/IN. ALLOW. CONST. STRESS= 108945 PSI

NO. OF LEAVES= 3
SPRING CONSTANT= 4921.66 LBS/IN. ALLOW. CONST. STRESS= 91281.5 PSI

LEAF THICKNESS AS FUNCTION OF X, INCH

FRONT		REAR	
X= .6	H2= .911249	X= .6	H3= .925936
X= 9	H2= .911249	X= 9	H3= .925936
X= 10.2	H2= .944744	X= 10.2	H3= .944744
X= 11.4	H2= .998772	X= 11.4	H3= .998772
X= 12.6	H2= 1.05002	X= 12.6	H3= 1.05002
X= 13.8	H2= 1.09889	X= 13.8	H3= 1.09889
X= 15	H2= 1.14567	X= 15	H3= 1.14567
X= 16.2	H2= 1.19062	X= 16.2	H3= 1.19062
X= 17.4	H2= 1.23392	X= 17.4	H3= 1.23392
X= 18.6	H2= 1.27576	X= 18.6	H3= 1.27576
X= 19.8	H2= 1.31628	X= 19.8	H3= 1.31628
X= 21	H2= 1.35558	X= 21	H3= 1.35558
X= 22.2	H2= 1.39377	X= 22.2	H3= 1.39377
X= 23.4	H2= 1.43094	X= 23.4	H3= 1.43094

AT EDGE OF FIXITY X= 24 IN., SEAT THICKNESS H1= 1.44917 IN.

WEIGHT = 45.7981 LBS.

Fig. 5-2. Computer Printout of Spring Program
(Rear Spring)

5.3.3 Configuration

The configuration of the rear spring assembly is shown in Figure 5-3. It consists of two steel leaves and three composite material leaves made of S2-glass fiber/epoxy. The fibers are oriented parallel to the length of the leaf. A +/- 5 degree fiber orientation was considered earlier in the program, but was abandoned when edge fiber delamination problems were encountered in both testing and fabrication.

Spacers made of woven fiberglass fabric are bonded to the leaves at the center to provide separation of the leaves and also to reinforce the hole for the center bolt. The bolt is used to align the leaves and to provide an indexing point for the seat clamp.

Stress concentration around the hole should be minimal. The seat clamp is long enough, 10.75 inches (273 mm), to ensure that there are no bending loads at the center of the leaf. There are no lateral loads on the leaf causing bearing stress on the composite laminate.

Rubbing pads of Teflon are bonded to the tips of the leaves to provide wear surfaces. The pads are bonded to both sides of the leaves so that the rubbing action is Teflon against Teflon. This ensures minimum friction and maximum protection for the laminate. The configurations of the individual composite leaves are shown in Figures 5-4, 5-5, and 5-6. Note that the drawings have not been revised to show 0 degree fiber orientation.

5.3.4 Weight

The weight of one composite leaf shown in Figure 5-3 is 16 lbs (7.3 kg). The weight of the assembled rear spring is 125 lbs (56.7 kg). This is 50 lbs (22.7 kg) less than the allowable maximum weight of 175 lbs (79.4 kg), and 168 lbs (76.2 kg) lighter than the current steel spring.

The weight savings over the current steel spring is then 57%.

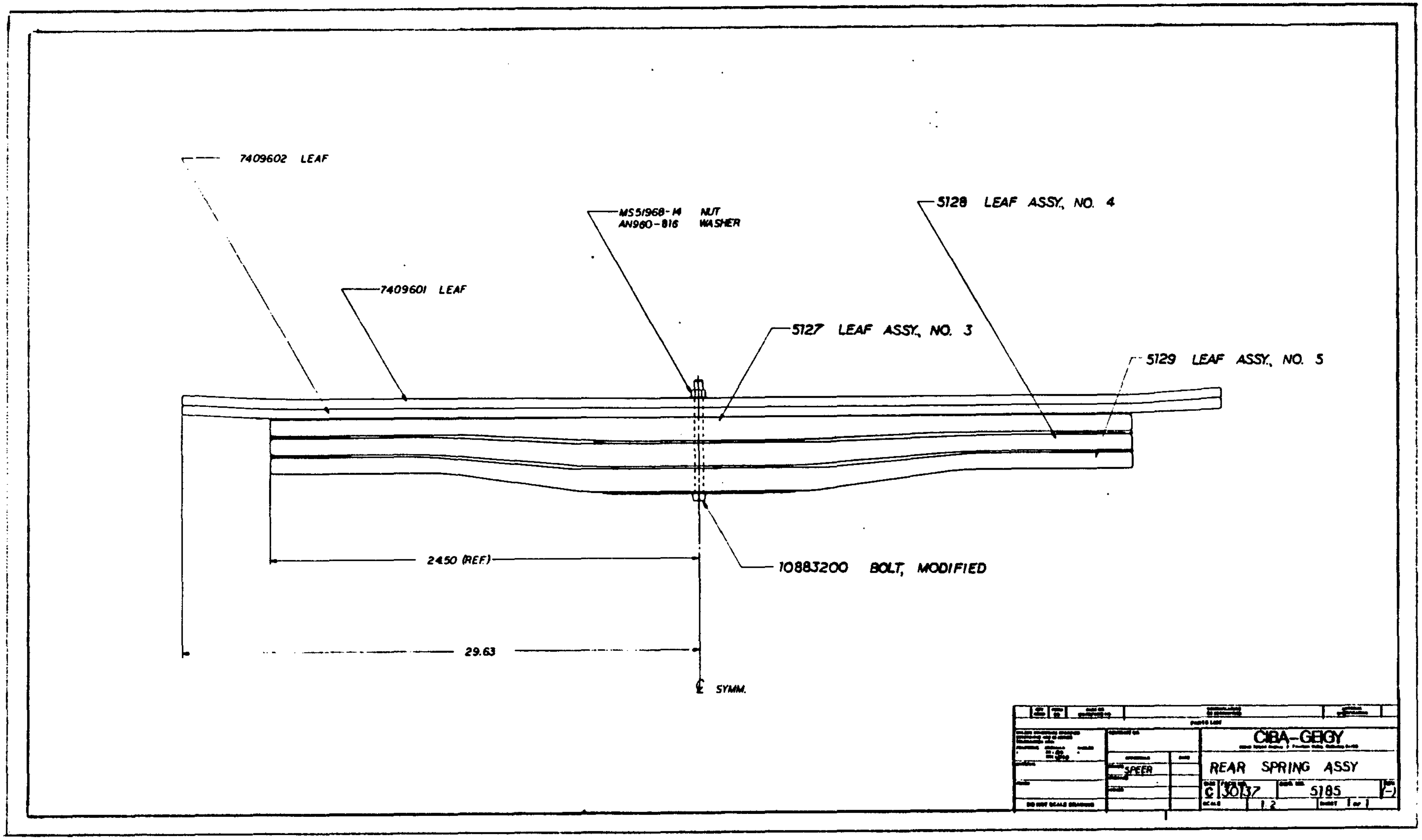


Fig. 5-3. Rear Spring Assembly

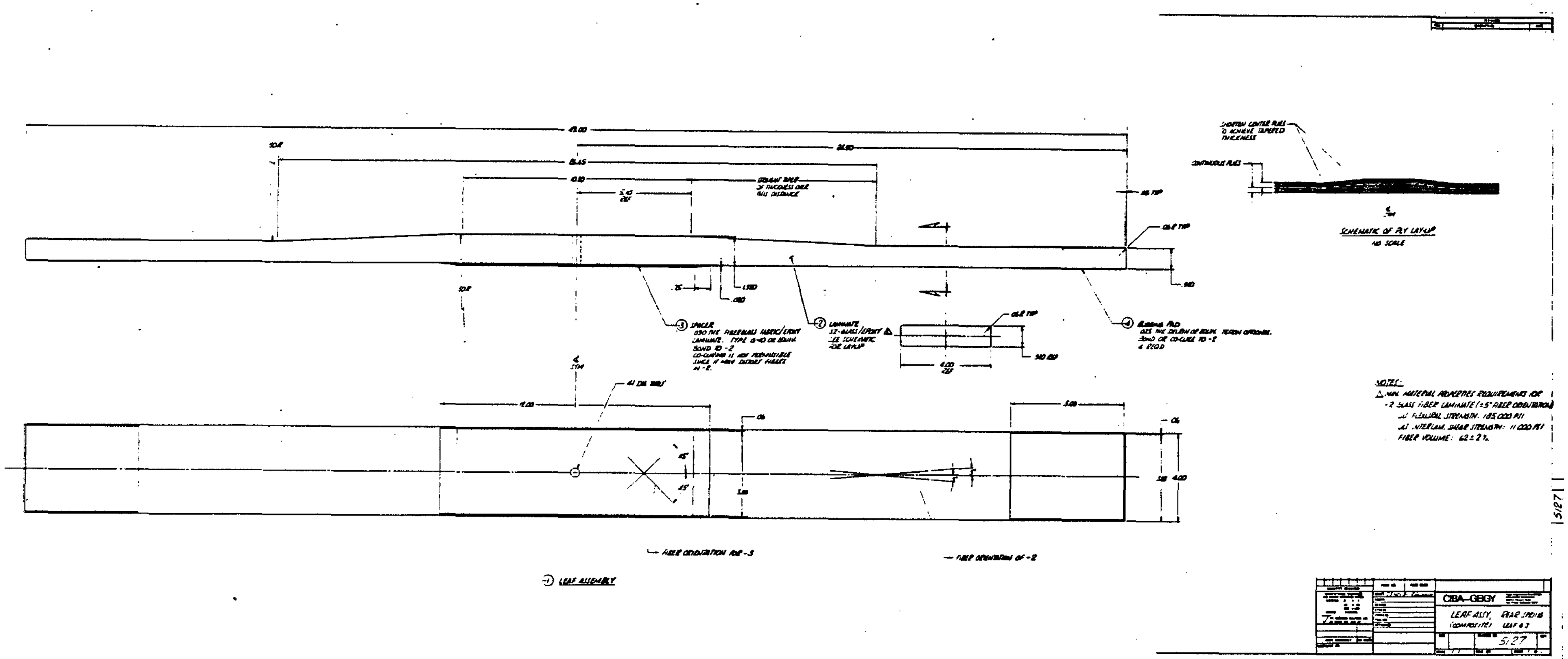


Fig. 5-4 Rear Spring, Leaf #3

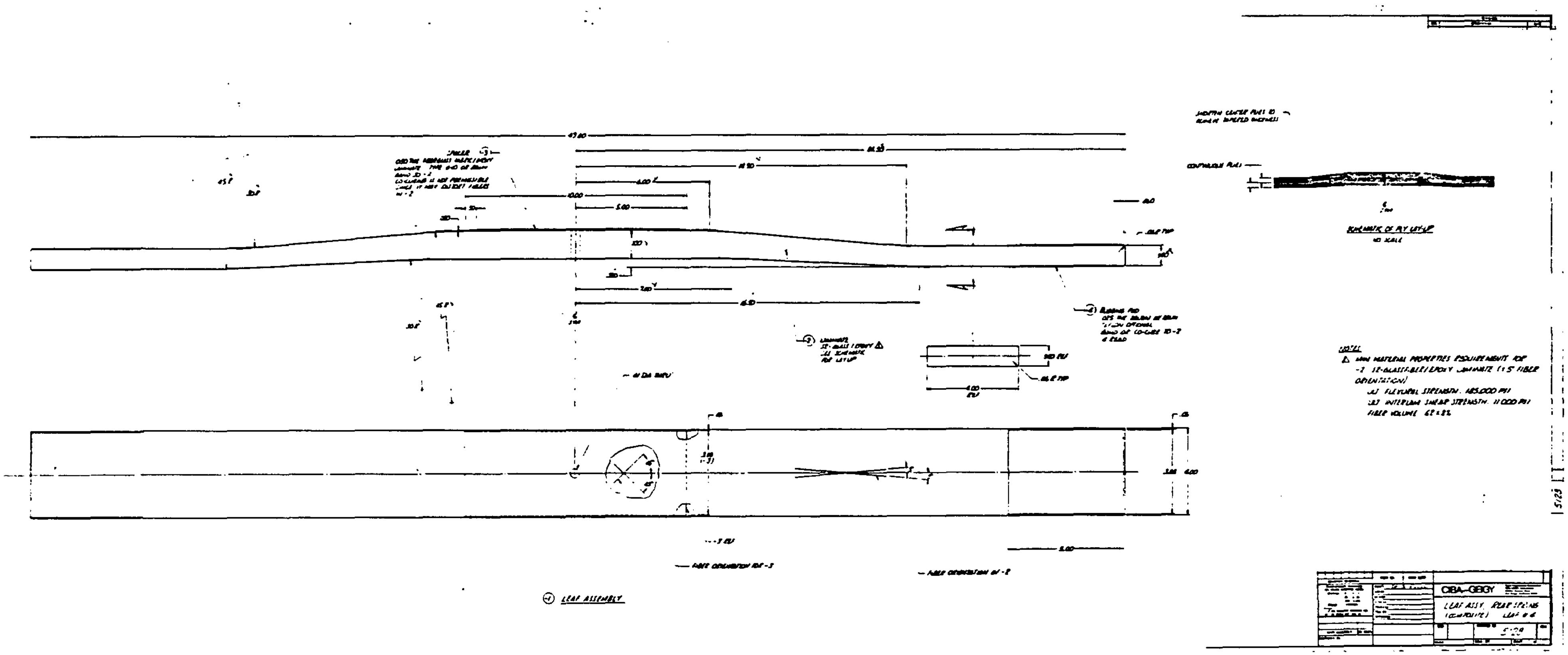


Fig. 5-5. Rear Spring, Leaf #4

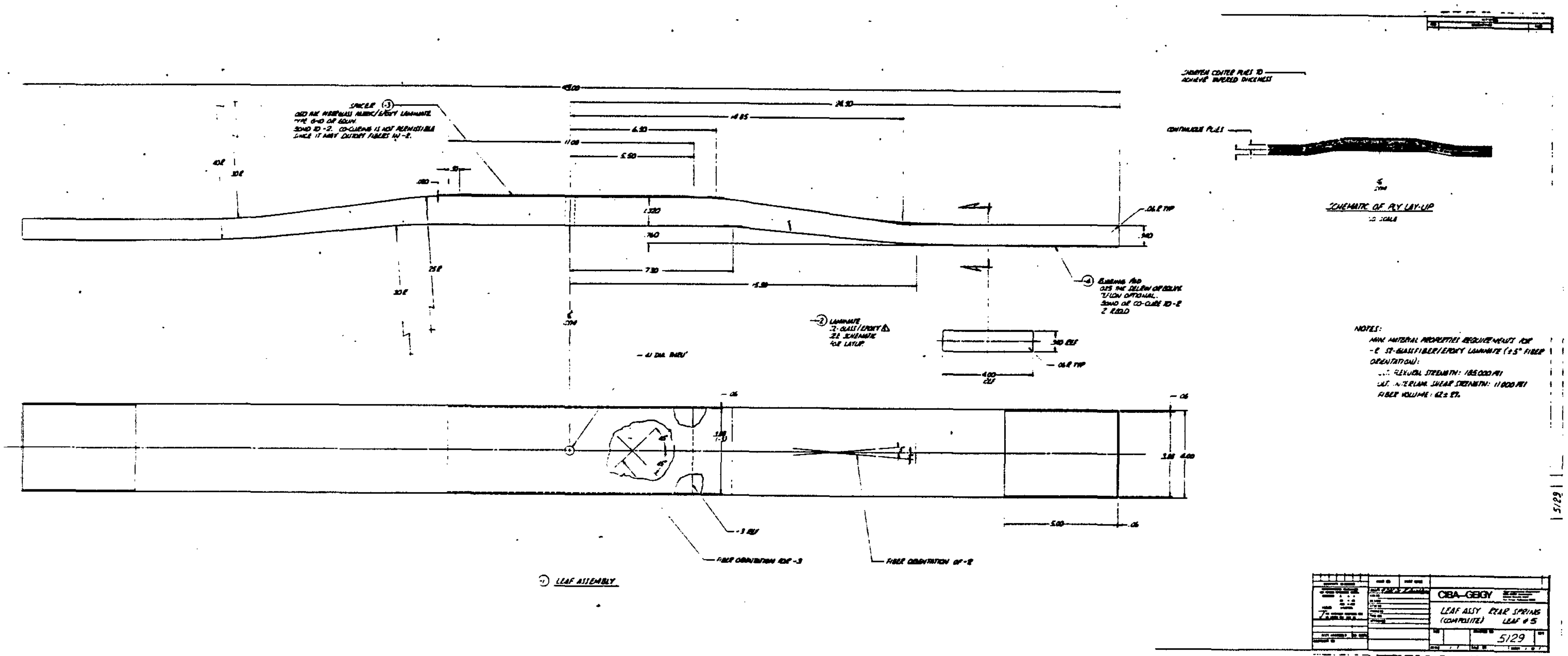


Fig. 5-6. Rear Spring, Leaf #5

5.4 Design - Phase II, Front Spring Assembly

The dimensions of the present steel front spring assembly are given on TACOM Drawing no. 7411110. The distance between he mounting eye and the center bolt is 25 inches (1635 mm) with the spring in a flat condition. The spring is symmetrical about its center line. The leaf width and thickness of the steel leaf are 3 inches (76 mm) and .447 inch (11 mm), respectively. The rebound leaf is .360 inch (9 mm) thick.

The two long leaves with mounting eyes and the rebound leaf in the steel spring assembly are used in the composite spring because of interchangeability requirements. The two steel leaves with eyes provide mounting points to the vehicle and fit into the existing support brackets.

Because of the much lower shear strength of the composite material when compared to steel, all composite leaves in the front spring were designed to have equal length. This is because shear stresses, rather than bending stresses, dictate the minimum thickness a commposite leaf can have at the tip. There were no envelope restrictions at the mounting brackets, so the composite leaves could be made the same length as the steel leaves.

The material and configuration of the composite leaves were selected from the results of the fatigue load study presented in Section 3. S2-glass fiber/epoxy and a leaf with tapered thickness was selected as the combination which would best satisfy both fatigue life requirements and geometric constraints.

5.4.1 Spring Deflection Rate

The required spring rate for the front spring assembly is 2271+/-135 lbs/inch (398 +/- 24 N/mm). To obtain the required spring rate for the composite leaves, it is necessary to know the spring rate of the two steel leaves and the rebound leaf.

The combined spring rate for the steel leaves was calculated to be 688 lbs/inch (121 N/mm).

The required rate for the composite leaves is then,

S/R = 2271-688 = 1583 lbs/in (277 N/mm).

Spring deflection,

at static load: 2.18 inches (55 mm)
at full jounce: 6.7 inches (170 mm)

Load on composite leaves,

at static load: 2.18 x 1583 = 3451 lbs (15,351 N)
at full jounce: 6.7 x 1583 = 10,606 lbs (47,178 N)

Axle torque is 165,270 inches-lbs (18,673 Nm) per spring

Axle torque is reacted at the mounting eyes.

Torque load at eye $\frac{165,270}{50}$ = 3305 lbs (14,703 N).

Torque load on composite leaves 3305 . $\frac{1583}{2271}$ = 2304 lbs (10,249 N).

This load is added as a tip load to one end of the composite leaves and subtracted from the other end.

A load/deflection diagram for the front spring assembly is shown in Figure 5-7.

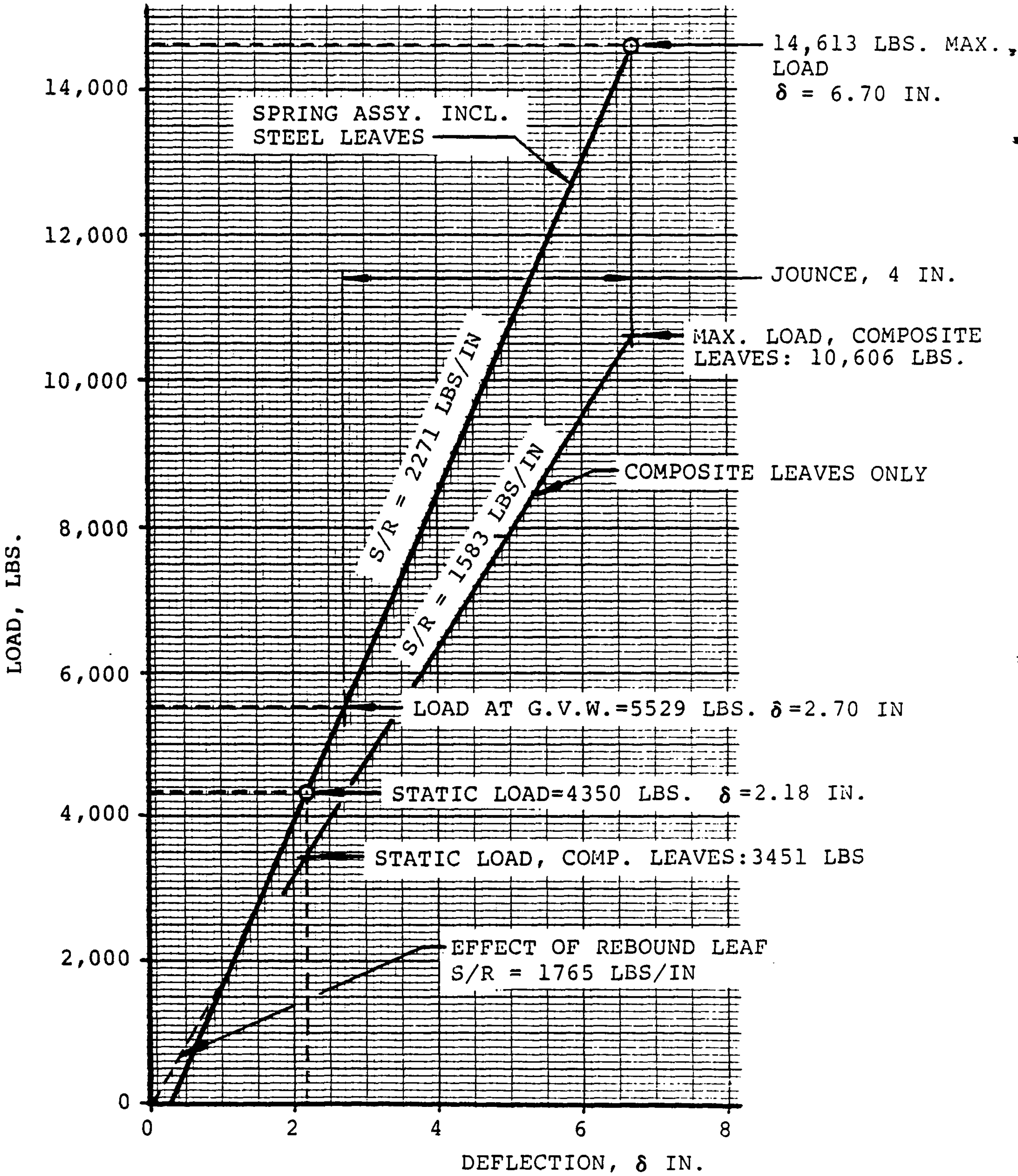


Fig. 5-7. Load/Deflection Diagram for Front Spring

5.4.2 Computer Analysis

The computer program used for the analysis of the front spring composite leaves is similar to that used for the rear spring and is described in paragraph 5.3.2. As was the case with the rear spring, a design with parabolic tapering of the leaf thickness and S2-glass fiber material was selected for the front spring composite leaves.

The program output, shown in Figure 5-8, shows a design consisting of two composite leaves of equal length and with identical thickness distribution. Also shown are calculated spring rate, bending stress, and combined weight of all composite leaves.

5.4.3 Configuration

Figure 5-9 shows the configuration of the front spring assembly. It consists of two steel leaves with eyes, one steel rebound leaf and two composite material leaves made of S2-glass fiber/epoxy. The fibers are oriented parallel to the length of the leaf. A +/- 5 degree fiber orientation was considered earlier in the program, but was abandoned when edge fiber delaminations problems were encountered in both testing and fabrication of the rear spring leaves.

Spacers made of woven fiberglass fabric are bonded to the leaves at the center to provide separation of the leaves and also to reinforce the hole for the center bolt. The bolt is used to align the leaves and to transmit lateral loads from the steel leaves to the seat clamp. Stress concentration around the holes in the composite leaves should be minimal.

The seat clamp is long enough (8.5 inches or 216 mm) to ensure that there are no bending loads at the center of the leaf. Lateral loads are transmitted from the seat clamp to the vehicle structure through the steel leaves. This design configuration minimizes bearing stresses between the bolt and the composite leaves.

Rubbing pads of Teflon are bonded to the tips of the leaves to provide wear surfaces. The pads are bonded to both sides of the leaves so that the rubbing action is Teflon against Teflon. This ensures minimum friction and maximum protection for the laminate. The configurations of the individual composite leaves are shown in Figures 5-10 and 5-11. Note that the drawings have not been revised to show 0 degree fiber orientation.

ARMY TRUCK FRONT SPRING, DWG. 7411110 (CONTRACT C-1249, PHASE II)

NO. 1, 2 AND REBOUND LEAVES STEEL
OTHER LEAVES S2-GLASS 4/-5 DEG./EPOXY

SOLID LAMINATE SPRING
PARABOLIC TAPER, CONSTANT STRESS

NO. OF LEAVES= 1
SPRING CONSTANT= 1619.53 LBS/IN. ALLOW. CONST. STRESS= 126227 PSI

NO. OF LEAVES= 2
SPRING CONSTANT= 1548.91 LBS/IN. ALLOW. CONST. STRESS= 96022.6 PSI

LEAF THICKNESS AS FUNCTION OF X, INCH

FRONT		REAR	
X= .625	H2= .732765	X= .625	H3= .743504
X= 6.875	H2= .732765	X= 6.875	H3= .743504
X= 8.125	H2= .748322	X= 8.125	H3= .748322
X= 9.375	H2= .803826	X= 9.375	H3= .803826
X= 10.625	H2= .855739	X= 10.625	H3= .855739
X= 11.875	H2= .904677	X= 11.875	H3= .904677
X= 13.125	H2= .9511	X= 13.125	H3= .9511
X= 14.375	H2= .995361	X= 14.375	H3= .995361
X= 15.625	H2= 1.03774	X= 15.625	H3= 1.03774
X= 16.875	H2= 1.07845	X= 16.875	H3= 1.07845
X= 18.125	H2= 1.11768	X= 18.125	H3= 1.11768
X= 19.375	H2= 1.15557	X= 19.375	H3= 1.15557
X= 20.625	H2= 1.19227	X= 20.625	H3= 1.19227
X= 21.875	H2= 1.22787	X= 21.875	H3= 1.22787
X= 23.125	H2= 1.26246	X= 23.125	H3= 1.26246
X= 24.375	H2= 1.29613	X= 24.375	H3= 1.29613

AT EDGE OF FIXITY X= 25 IN., SEAT THICKNESS H1= 1.31264 IN.

WEIGHT = 20.8663 LBS.

Fig. 5-8. Computer Printout of Spring Program

(Front Spring)

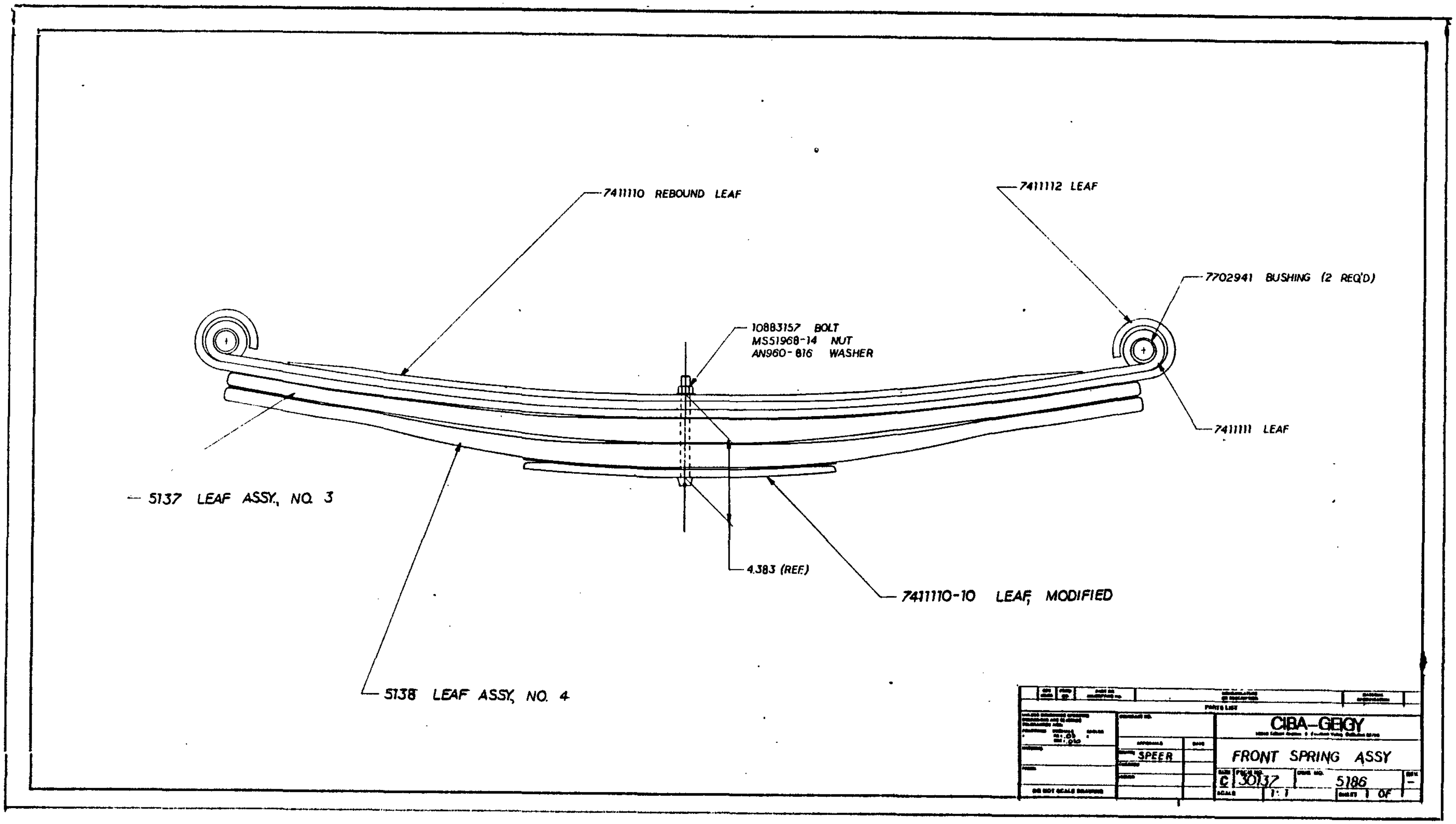


Fig. 5-9. Front Spring Assembly

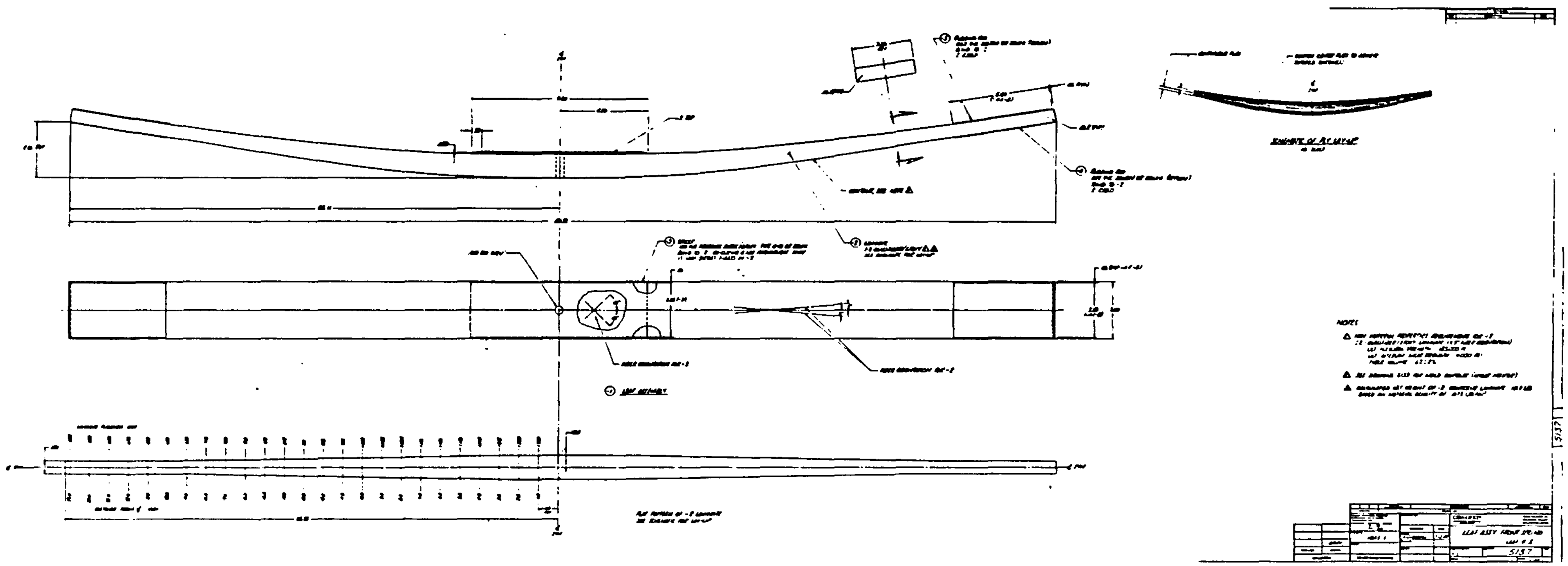


Fig. 5-10. Front Spring, Leaf #3

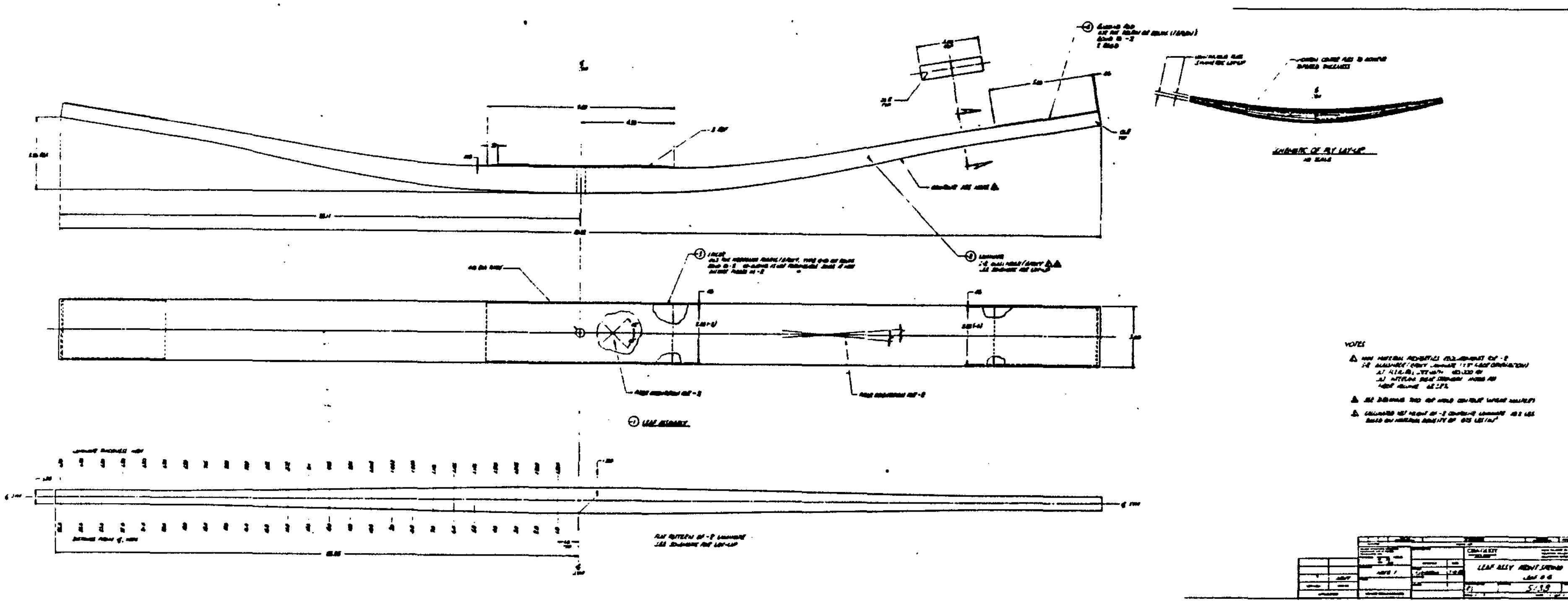


Fig. 5-11. Front Spring, Leaf #4

Late in the program, a modification was made to the front spring assembly in that a short steel leaf was added to the underside of the lower composite leaf. This was prompted by a reported failure in the rear spring, apparently caused by high stress concentration in the composite leaf at the edge of the seat clamp. The short steel leaf will provide a smoother transition between seat clamp and composite leaf. The short leaf used is number 10 leaf in the steel front spring assembly. It is 15.75 inches (400 mm) long and, therefore, it protrudes 3.6 inches (91 mm) beyond the seat clamp. A 5 degree chamfer, approximately 1.5 inches (38 mm) long, and a corner radius were machined in the leaf on the side which is adjacent to the composite leaf. This will ensure that there are no sharp ponts in contact with the composite leave as the spring is deflected. A .032 inch (.8 mm) thick sheet of Teflon, 17 inches (432 mm) long by 2.75 inches (70 mm) wide, bonded to the lower composite leaf provides a separation and wear surface with the short steel leaf.

5.4.4 Weight

The weight of one composite leaf shown in Figure 5-9 is 10.5 lbs (4.8 kg). The weight of the assembled front spring is 85 lbs (39 kg). This is 5 lbs (2.3 kg) less than the allowable maximum weight of 90 lbs (41 kg), and 64 lbs (29 kg) lighter than the current steel spring. The weight savings over the current steel spring is then 43%.

6. Fabrication of Prototype Leaf Springs

6.1 Introduction

The program involved the fabrication of 10 rear spring assemblies (Phase I) and 10 front spring assemblies (Phase II). The composite leaves in the assembly were to be fabricated using a process which would be capable of producing 25 sets (50 spring assemblies) per day. For this purpose, a number of different manufacturing processes were evaluated. As a rule, when designing with composite orthotropic materials, manufacturing processes are considered to a much larger degree than is usually the practice with conventional isotropic materials. In this case, performance requirements limited the number of design configurations and, therefore, also eliminated some manufacturing processes from consideration.

6.2 Manufacturing Process Evaluation

A spring leaf consists of essentially unidirectional fibers oriented parallel to the length of the leaf, and embedded in a structural resin matrix. The fibers resist tension and compression resulting from bending forces. The resin transfers shear loading between adjacent fiber layers, and also supports fibers undergoing compression and thus prevents buckling. After the resin solidifies from heat and pressure applied during molding or forming, the resulting laminate exhibits high strength in the direction of the fibers. However, strength perpendicular to the fibers is relatively low. If required properties in directions perpendicular to the fibers can be improved by arranging some of the fibers in the desired direction, or by arranging layers of fibers which cross each other at alternating angles (such as + and - 5 degrees) to the longitudinal axis. The properties in the longitudinal direction will then be reduced.

Application of resin to the fiber can be performed in a separate operation prior to lay-up on the tool (pre-impregnated), or the fiber can pass through a batch of resin at the time of lay-up (wet lay-up). Preimpregnation is usually performed by specialty houses specializing in this process. The fiber is then supplied to the user in the form of rolls or narrow tape or broadgoods. In this form, the material is laid up on the tool by automated type laying machines, or it is cut into patterns prior to depositing on the tool. The resin in the prepreg is slightly cured to form a tacky surface, but it does not run. The amount of resin deposited on the fiber is closely controlled. For very large productions, the pre-impregnation process can be made a part

Wet impregnation is performed at the time of lay-up of the fiber on the tool. The most common wet lay-up process is filament winding where the fiber tow is wound over a mandrel of the desired shape after it has passed through a bath of liquid resin. A series of rollers squeeze out excess resin from the fiber before it is deposited on the mandrel.

Three different fabrication processes, considered practical for the manufacture of the spring leaves, were evaluated.

- Filament winding
- Pultrusion
- Ply lamination and compression molding.

6.2.1 Filament Winding

Filament winding consists of depositing a continuous fiber strand over a rotating mandrel while guiding the fiber back and forth along the axis of rotation to achieve the desired winding angle and build up of material. For a spring leaf, which consists of a slightly curved, narrow beam with the fiber oriented along the length of the beam, the winding mandrel would be shaped such that one winding operation would produce two or more leaves. The concept is shown in Figure 6-1. Constant thickness is easier to produce, but a tapered thickness leaf, as in the selected design, can be produced as shown in the illustration. To achieve the desired fiber volume, material properties, and dimensional control, it is necessary to cure the wound laminate under heat and pressure in a closed, matched die. The mandrel over which the fiber was wound forms a part of the mold. After curing, the ends of the loop are cut off so that the part can be removed from the tool. Either pre-impregnated fiber or wet winding may be used for this operation.

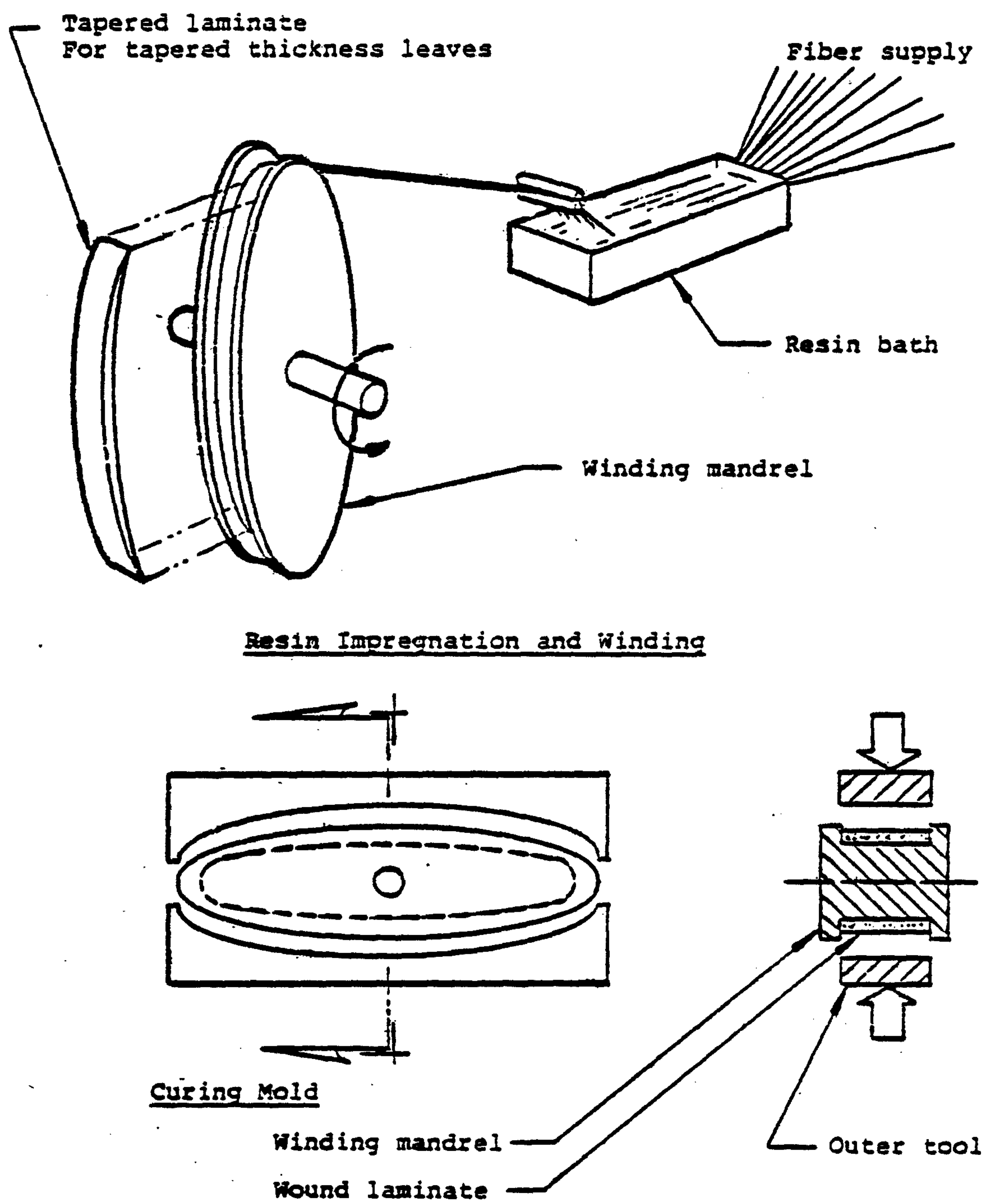


Fig. 6-1 Filament Winding of Spring Leaf

6.2.2 Pultrusion

The pultrusion method of fabricating composite components consists of pulling continuous resin impregnated fibers through a ceramic die to produce a given cross section. As the resin-impregnated material is drawn through the die, it is cured rapidly by R.F. heating. Pultrusions are normally produced in straight, continuous sections but with proper tooling the process is capable of producing parts with varying cross sectional shape or with curvature, as long as the volume of fibers drawn through the die is held constant. The material is 90% cured at the time it comes out of the die and, therefore, reshaping of the part is limited to minor changes.

The pultrusion process is usually performed with polyester resins, which process much more easily in pultrusion than other resins. Polyester resin systems can be pultruded 10 times faster than epoxy resin systems.

The process of pultruding and forming the part in one operation is called pulforming. A pulforming concept is depicted in Figure 6-2. The pulforming machine was developed and built by Goldsworthy Engineering in Torrance, California. This process is still in the developmental stage.

6.2.3 Compression Molding

Compression molding of ply laminations involves molding of pre-impregnated plies in a heated, matched metal mold. The process requires that individual patterns be cut from broadgoods sheets and placed in the mold. The patterns may be cut from pre-plied sheets consisting of as many as 10 plies. Thickness tapering, such as that of an automotive spring leaf, is accomplished by stacking plies of different lengths. These plies must be cut and stacked as individual plies to minimize the effect of the steps. The process can be automated. Machines which will cut and stack patterns in a predetermined sequence, are available. The equipment shown in Figure 6-3 is being manufactured by Century Design, Inc., in San Diego, California. At present, the machine requires a manual setting of the pattern length. A computer controlled operation, where the length and placement of the pattern can be programmed, is under development.

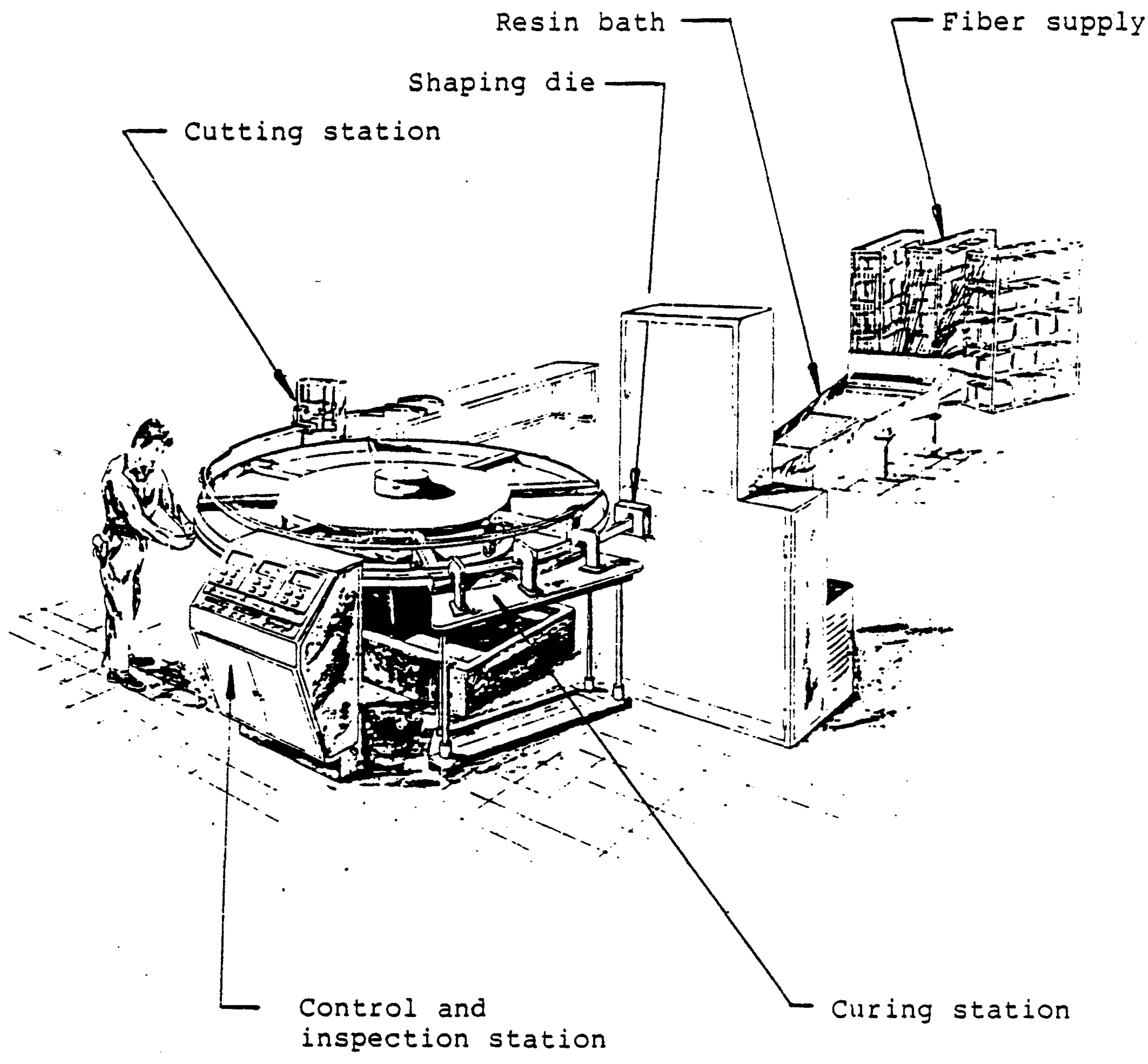


Fig. 6-2. Pulforming of Spring Leaves

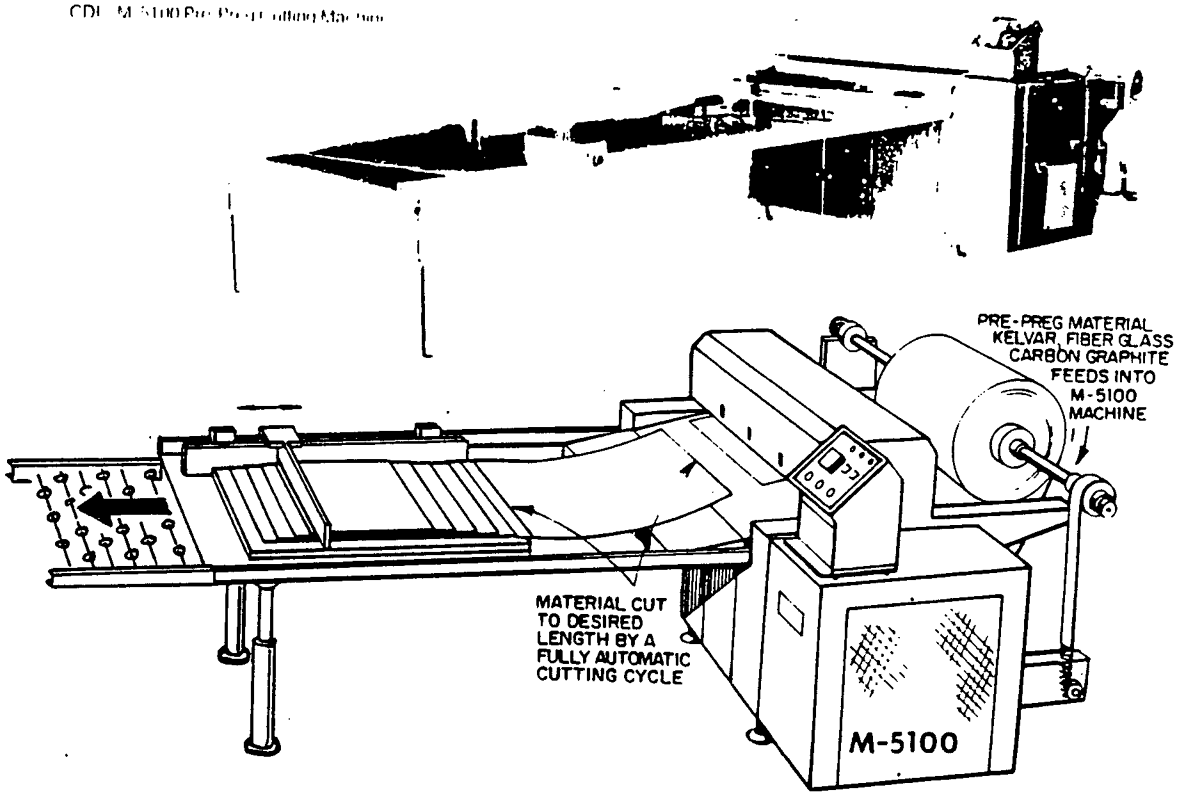


Fig. 6-3. Cutting and Stacking of Prepreg Patterns

For very thick laminates, as in the spring leaf, the stacked prepreg must be compacted or debulked in stages before it is placed in the mold. This is normally done under a vacuum at room temperature or slightly elevated temperature in stack thicknesses of 1/2 inch (13mm) or less. The purpose of the debulking is to remove trapped air between the plies, which could result in voids in the cured laminate.

For economic reasons, the mold should be large enough to produce a laminate from which 10 leaves could be cut. This requires a large press. A laminating pressure of 100 psi (690 KPa) on this type of mold for the rear spring leaves requires a press with 125 tons capacity. The press platens have to be a minimum of 5 x 5 feet (1.5 x 1.5 m) in size to accommodate the tool.

Curing time and temperature requirements depend on the resin formulation. Short time curing systems have also short "out-life", the time from cold storage to curing. This presents no problem in an automated fabrication process, where the material flows rapidly. For prototype fabrication, however, where hand lay-up methods are substituted for automation, the "out-time" may be as long as several days. The resin system must then be formulated accordingly, and the curing time here may be as long as 3 to 4 hours at 250 degrees F (121 degrees C). For an automated process the resin would be formulated for a curing time of around 15-20 minutes at temperatures from 300 to 400 degrees F (149 to 204 degrees C). The part may then be removed from the tool and post-cured in an oven, thereby releasing the mold for the next laminate. Turnaround time for the mold can thus be minimized. The compression molding process is shown in Figure 6-4.

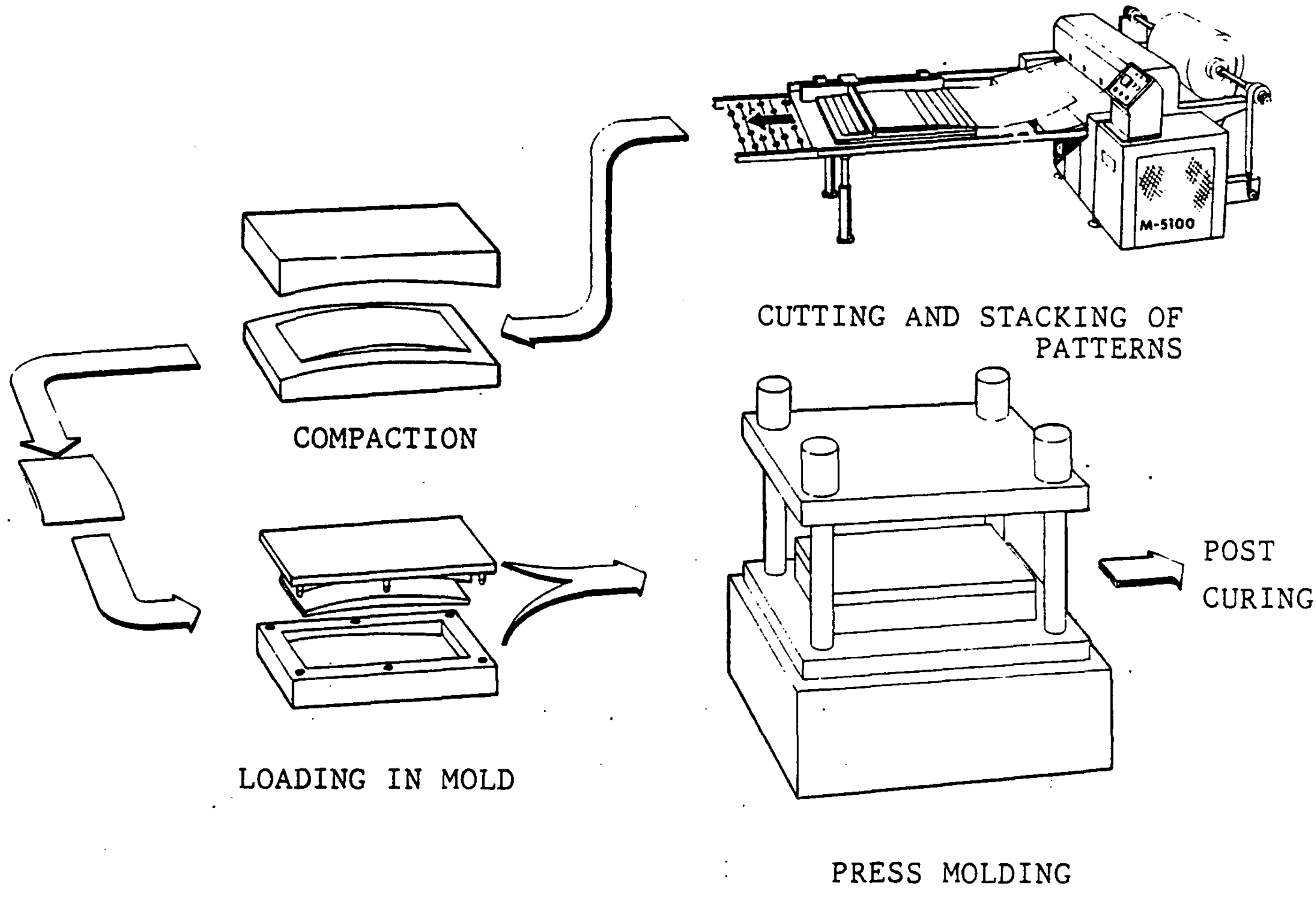


Fig. 6-4. Compression Molding Process

6.2.4 Machining of Laminates

After curing, the laminates would be sliced into individual leaves. Each leaf would then have its ends trimmed and a corner radius machined along the cut edges to reduce stress concentrations. This process would be identical for a compression molded or a filament wound multi-leaf laminate. The process can be automated as shown in Figure 6-5.

After inspection, Teflon pads and woven fiberglass spacers would be bonded to the leaf. The Teflon pad would then be temporarily masked off, and a polyurethane coating applied to the leaf. The leaf would then be assembled together with other leaves to form a spring assembly.

6.2.5 Selection of Fabrication Process

The compression molding process, described in paragraph 6.2.3, was selected as the most suitable process for the manufacture of the composite spring leaves. The process can be almost fully automated and there are no steps requiring developmental work. The traditional and proven process of hand-cutting patterns and lay-up in a mold can be directly translated into automation, accurately repeating an established operation without risk of human errors, thereby meeting the requirement of producing springs with consistent properties.

The filament winding process is also well established, but it was felt that some development would be needed to adapt the process for manufacturing tapered leaves.

Pultrusion or pulforming of spring leaves is still in the development stage.

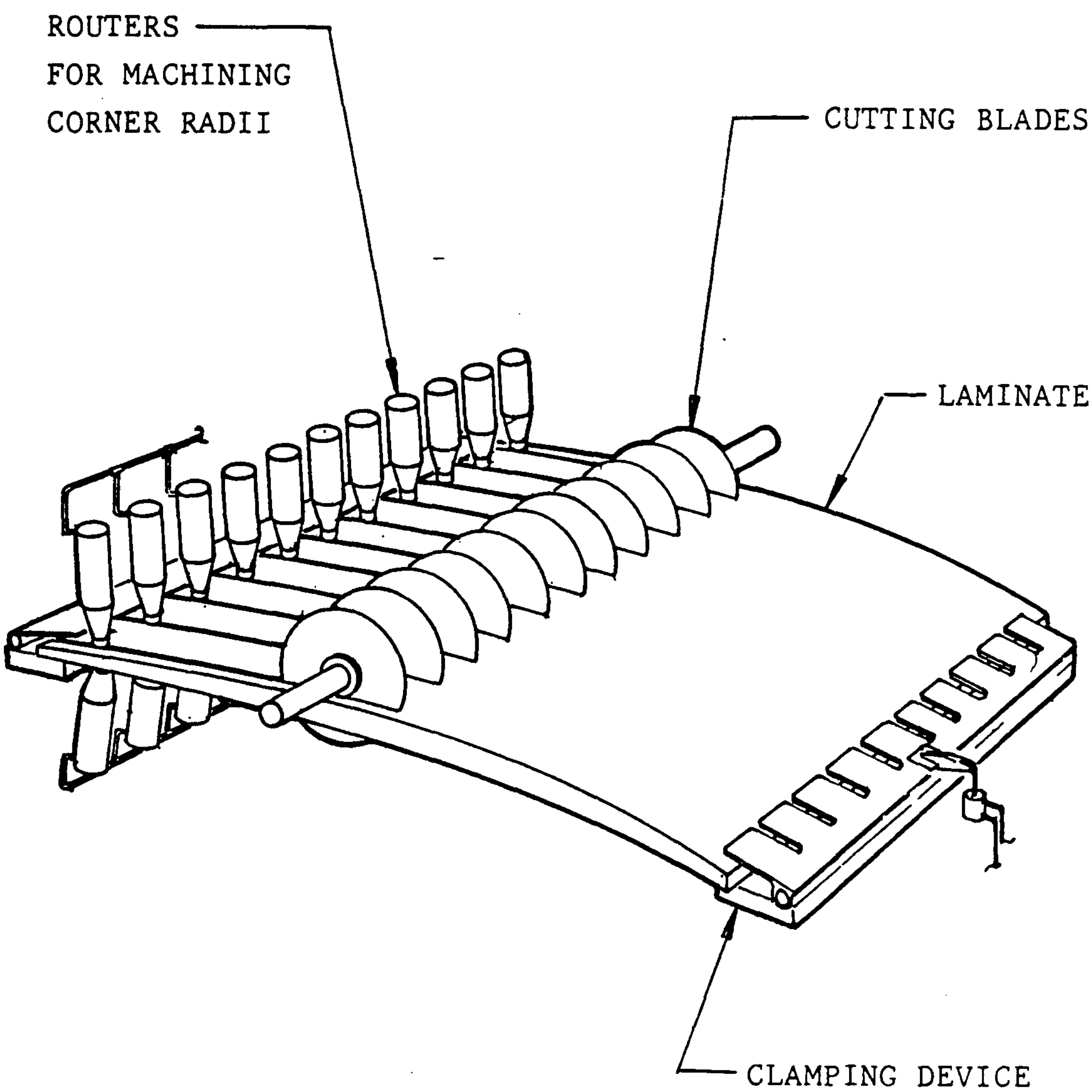


Fig. 6-5. Slicing and Routing of Laminate

6.3 Fabrication - Phase I, Rear Spring

6.3.1 Tooling

The three composite leaves in the rear spring assembly were fabricated in matched molds made of aluminum. Each mold was of different width. The reason was to evaluate the feasibility of molding laminates or billets of widths from which several leaves could be obtained. The mold for the lower leaf produced a laminate 18 inches (457 mm) wide. From this laminate, four 4-inch (102 mm) wide leaves could be cut. The mold for the center leaf produced one leaf at a time and the mold for the upper leaf produced 2 leaves.

The size of the mold did not appear to affect the quality of the laminate. Good laminates were produced from each tool. Handling of the larger tool sometimes presented a problem. On several occasions, the tool had to be disassembled in order to remove the laminate, which meant that the tool had to be removed from the press. This operation is difficult without proper equipment since the tool weighs in excess of 700 lbs (317 kg). At least two laminates were damaged as a result of improper handling of the tool. This problem would not exist with proper production tools and equipment. Features for reliable ejection of the part from the tool would be incorporated and handling equipment would be available.

The molding surfaces were hard-anodized for better wear resistance. Each mold half was electrically heated by rod heaters embedded in the base. The heaters were controlled by thermostats. A 2 degree draft angle was incorporated in the female mold half of the large tool later in the program to facilitate removal of the part.

Figure 6-6 shows the large mold installed in the press. Figures 6-7 and 6-8 show the molds for leaves number 4 and 5.

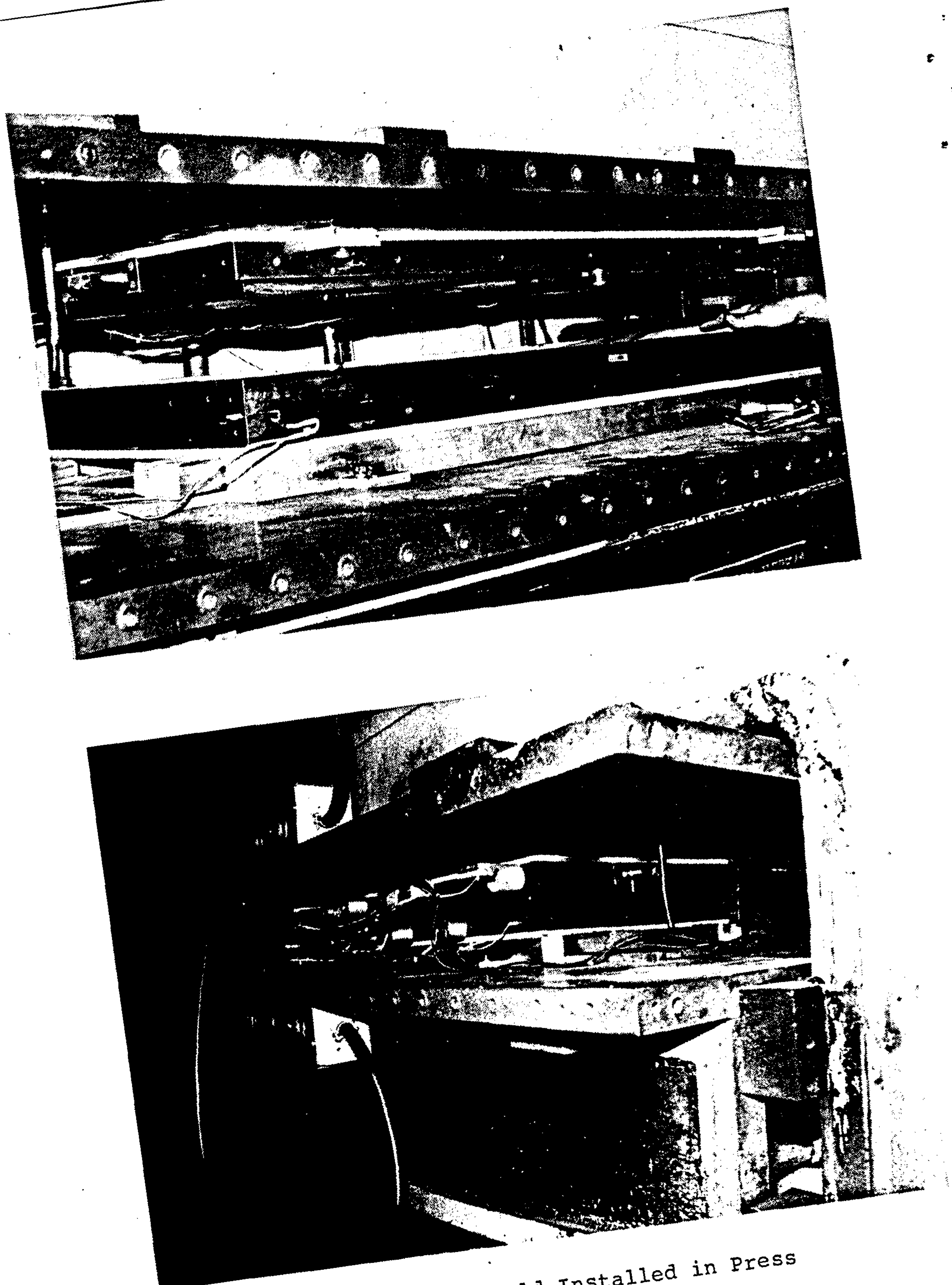


Fig. 6-6. Mold Installed in Press

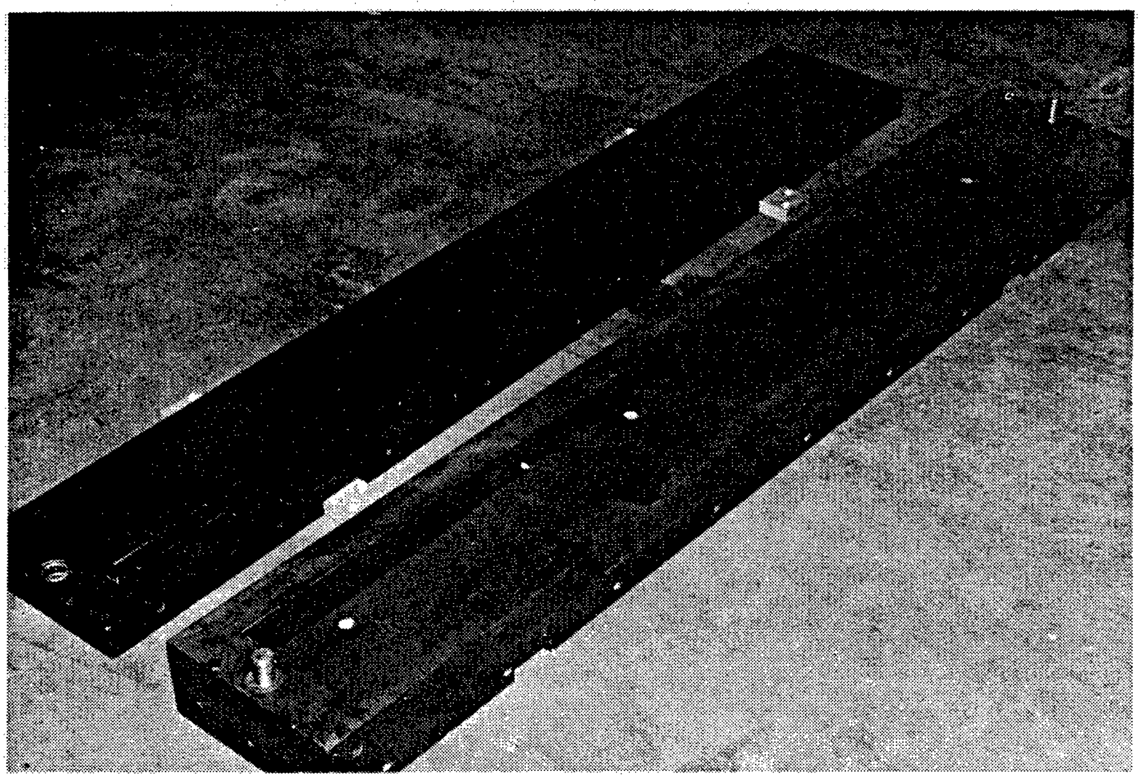


Fig. 6-7. Mold, Rear Spring Leaf #4

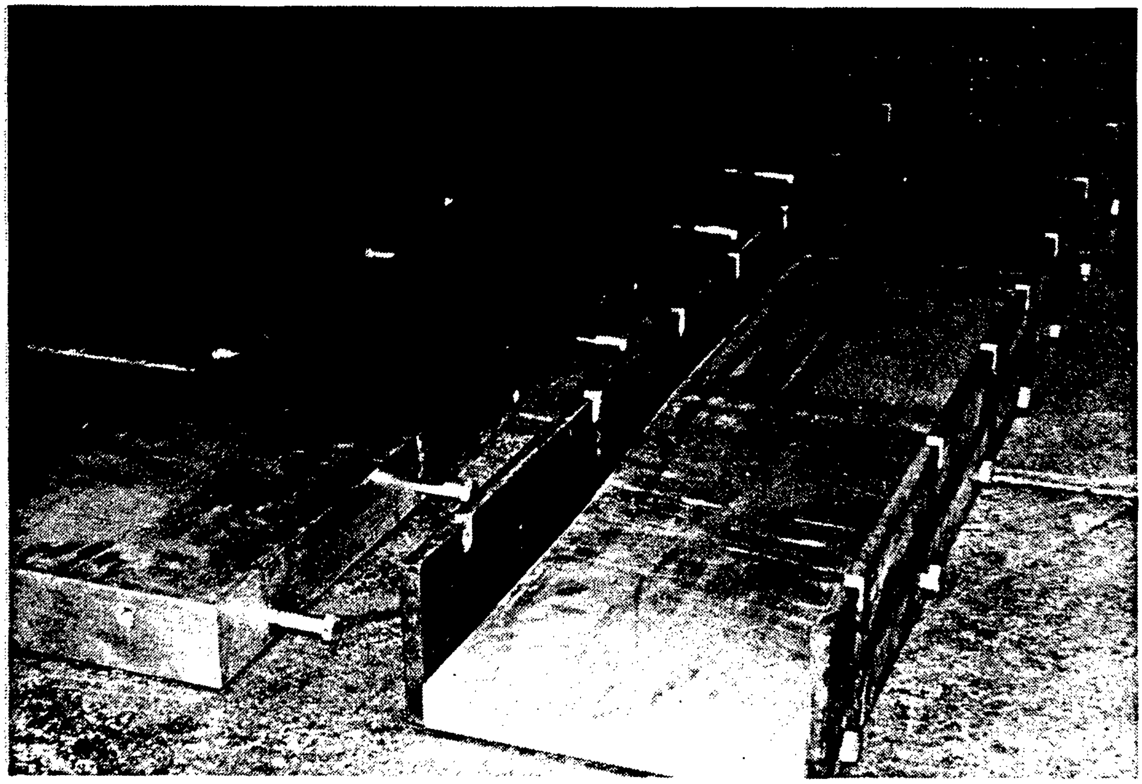


Fig. 6-8. Mold, Rear Spring Leaf #5

6.3.2 Component Fabrication

Individual plies were cut from a 42 inch (1067 mm) wide roll of S2-glass fiber/epoxy prepreg. The lay-up was done in three phases. The lower and upper layers consist of full length plies, while the center layer provides the thickness tapering. The taper was achieved by cutting and stacking plies of different lengths. The shorter plies in the tapered section were placed in the center with successively longer plies placed on either side of the center line. Each ply was positioned carefully on the stack to ensure parallelity of the fibers and symmetry of the taper about the center line. This was aided by the fact that a prepreg with net resin content was used and, as such, was not very tacky. The ply did not stick immediately to the next ply and allowed sliding the ply into the correct position before applying a slight pressure for permanent adhesion.

A system was devised to ensure the correct count of plies in each stack. This operation must be very carefully controlled in a hand lay-up process to achieve consistent properties in the laminate. There are 150 plies in each leaf and the risk for human error exists. In an automated, computer controlled operation, this risk would be eliminated. As a check of the number of plies, each stack was weighed and compared with an established weight.

Each stack of plies was debulked under a vacuum before it was placed in the mold. A vacuum release cloth was placed between the mold surface and the laminate. No bleeder cloth was used since there was little or no excess resin in the prepreg. The small amount of excess resin filled the cavities between the mold sides and the laminate. The lay-up was cured at 100 psi (690 KPa) and 250 degrees F (121 C).

In a closed, matched mold the pressure on the laminate is a calculated pressure. The calculation is based on a known thickness of a cured ply. The desired molding pressure is then converted to a press load. At the time the mold is fully closed, the press load is observed and recorded. Large deviations from the pre-determined load would indicate an incorrect number of plies in the laminate.

The mold was allowed to cool down before the laminate was removed. In a production set-up the tool would be designed with a rapid cooling system and only cooled to a temperature where the laminate could be handled easily and removed without causing damage. A molded billet from the large tool is shown in Figure 6-9.

The laminate was then cut into leaves of the desired width. The cutting was done with a 10 inch diameter water cooled diamond coated saw. The arrangement is shown in Figure 6-10. The cut surfaces were inspected for voids and discontinuties in the fibers. The sharp edges left by the cutting operation were then radiused. A generous radius along the edges of the leaf is necessary to prevent stress concentration. An abrasive routing tool producing a 3/16 inch (5 mm) radius was developed and the cutting was performed in a water spray. It was found that a carbide tipped router bit had a tendency to delaminate the outer plies. Further development of this tool is necessary to assure a smooth operation in a production set-up.

Spacers made of laminated E-glass fabric/epoxy were cut to size, chamfered along the ends, and bonded with adhesive to each leaf. Wear pads of Teflon were cut to size and also bonded with adhesive to the tips of the leaves. Bonding of Teflon requires special procedures to achieve good adhesion. It also requires a locating fixture to prevent the pad from sliding when pressure is applied. Figure 6-11 shows the locating fixture as used on a front spring leaf. After drilling the bolt hole through the center of the leaf, the Teflon pads were masked off and the leaf was spray-coated with polyurethane.

A step by step procedure for fabrication of the composite leaves is included in Appendix A.

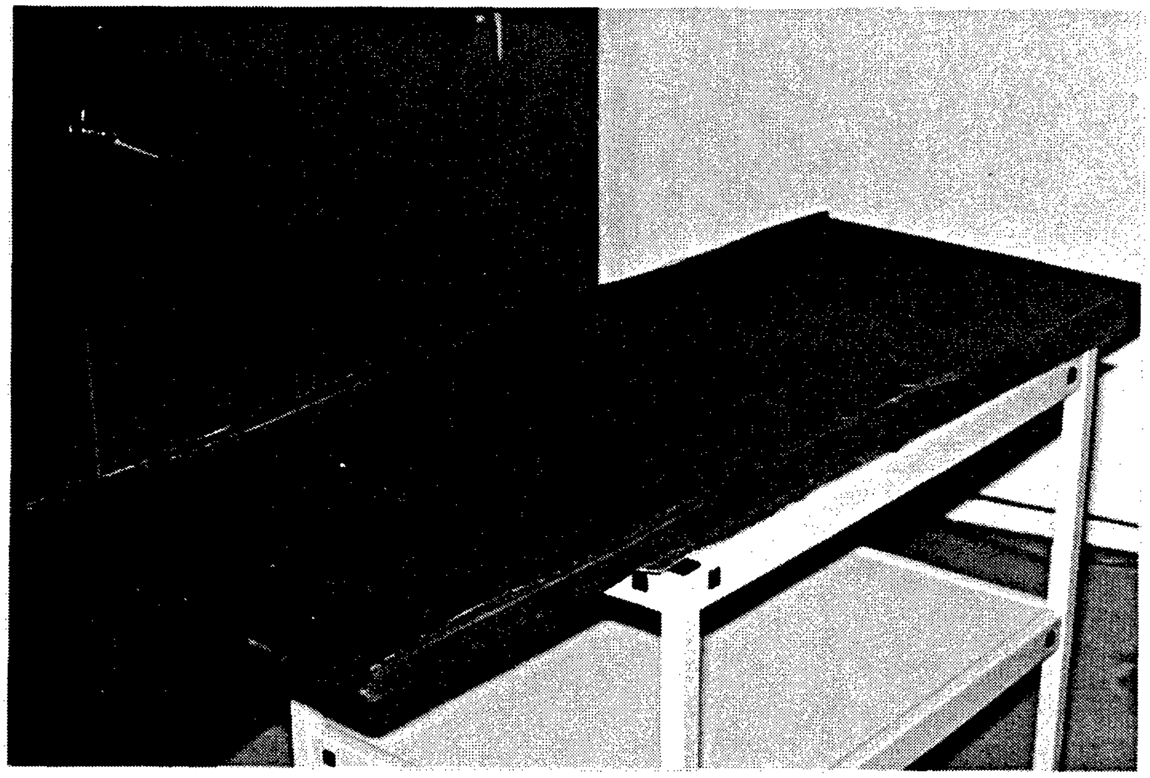


Fig. 6-9. Molded Billet

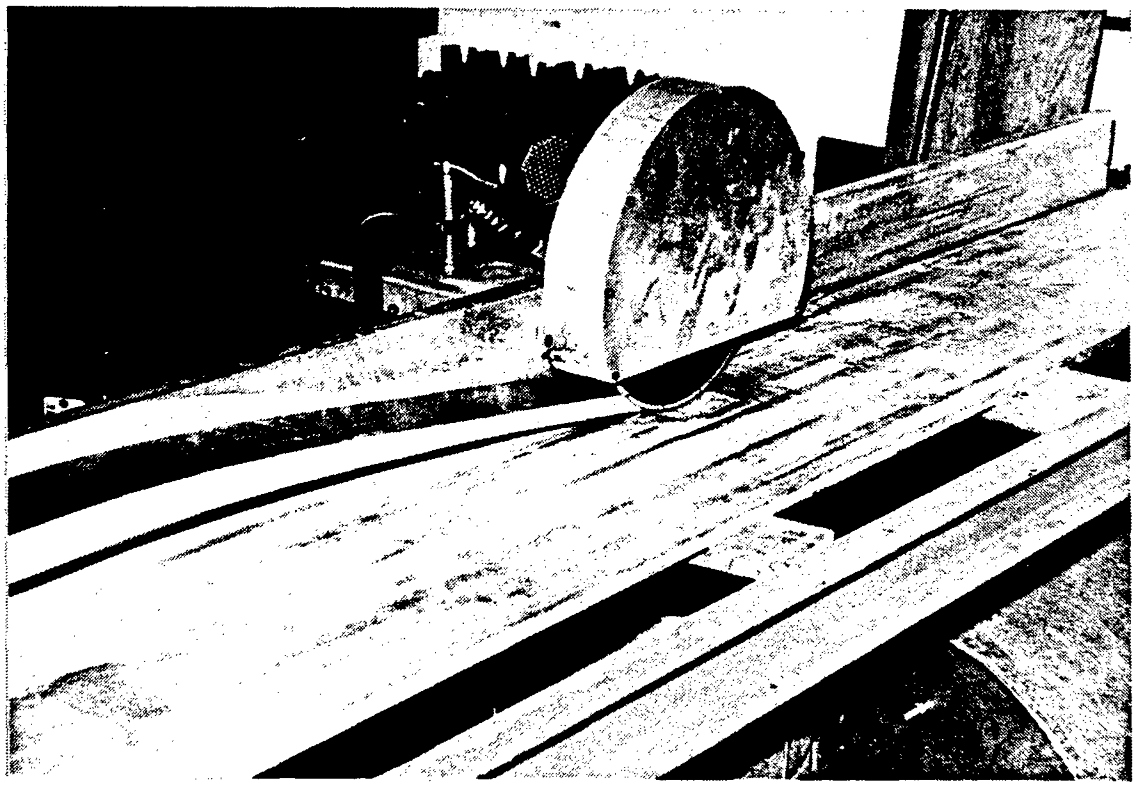


Fig. 6-10. Cutting of Laminate

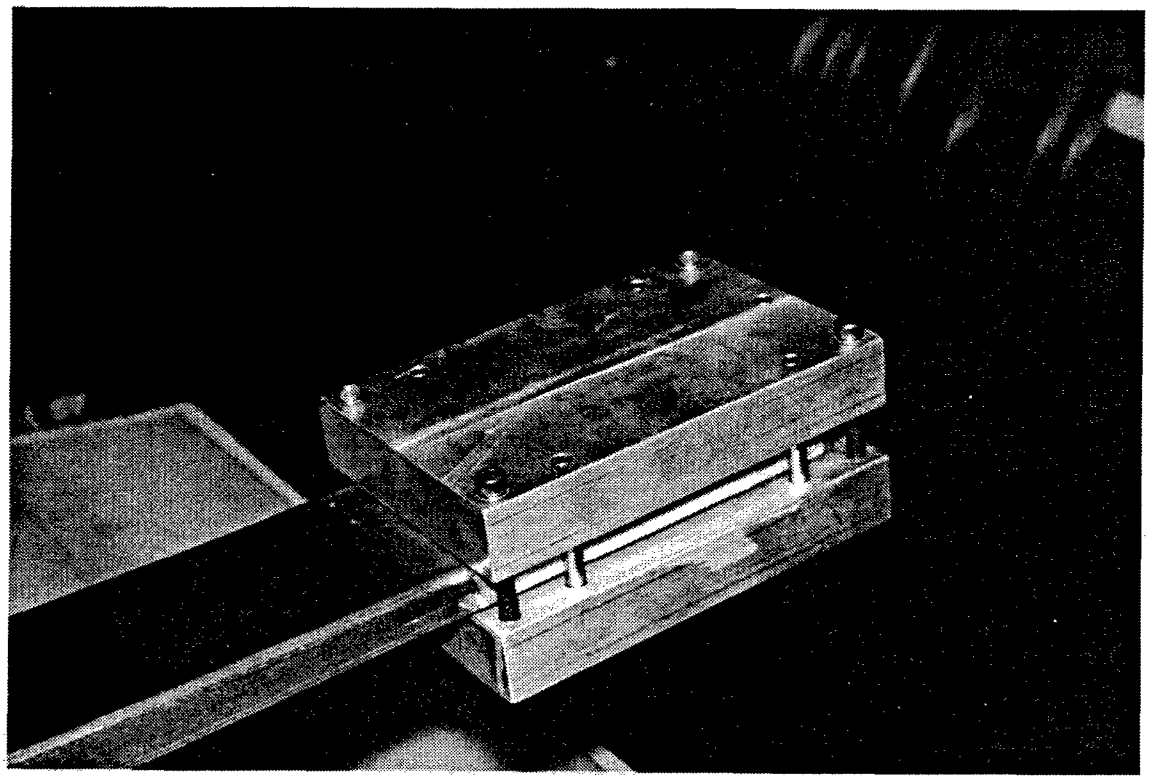


Fig. 6-11. Fixture for Positioning and Bonding of Wear Pad

6.3.3 Assembly

The three composite leaves were assembled to two steel leaves in accordance with the assembly drawing shown in Figure 6-12. The two steel leaves were obtained from the existing steel spring assembly, Ordnance Part no. 7409613. Ten of these assemblies were purchased from Rockwell International, Suspension Components Division, Troy, Michigan. No alterations were made to these leaves. The center bolt in the steel spring assembly was also used in the composite assembly. Because of the shorter clamping length required for the composite assembly, the bolt was shortened and re-threaded.

The clips used in the steel spring assembly to keep the leaves aligned during handling and installation were not used on the composite assembly. Attaching the clips to the composite leaves with mechanical means, such as bolting, presents a problem in that it weakens the area of the leaf which is designed for maximum shear stresses. Attaching the clip with adhesive was not considered practical. It would be possible to weld the clip to one of the steel leaves, if this operation is performed prior to heat treatment and shot peening of the leaf.

Ten springs were assembled and shipped to TACOM, Warren, Michigan, for testing. The rear spring assembly is shown in Figures 6-13 and 6-14.

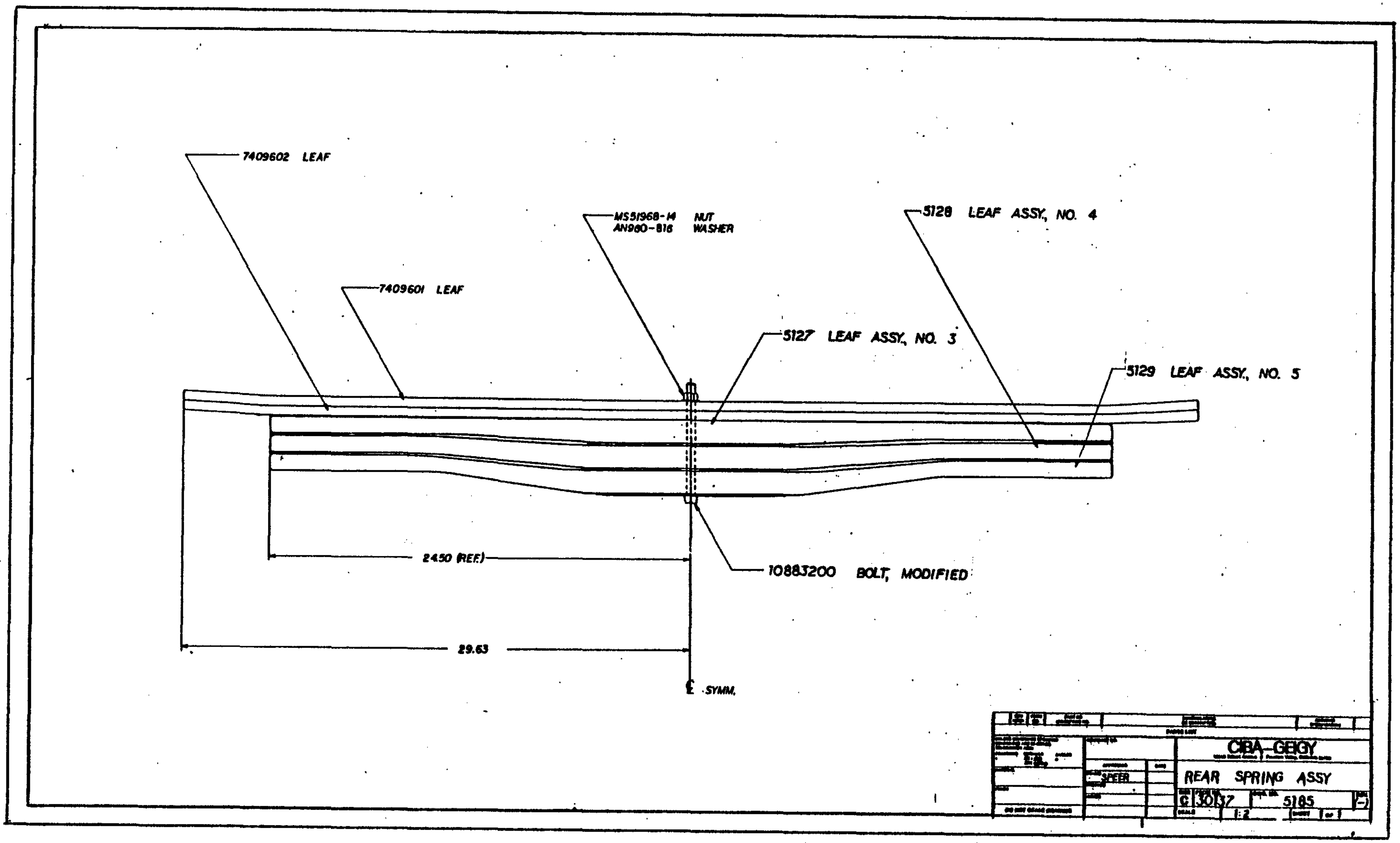


Fig. 6-12. Rear Spring Assembly

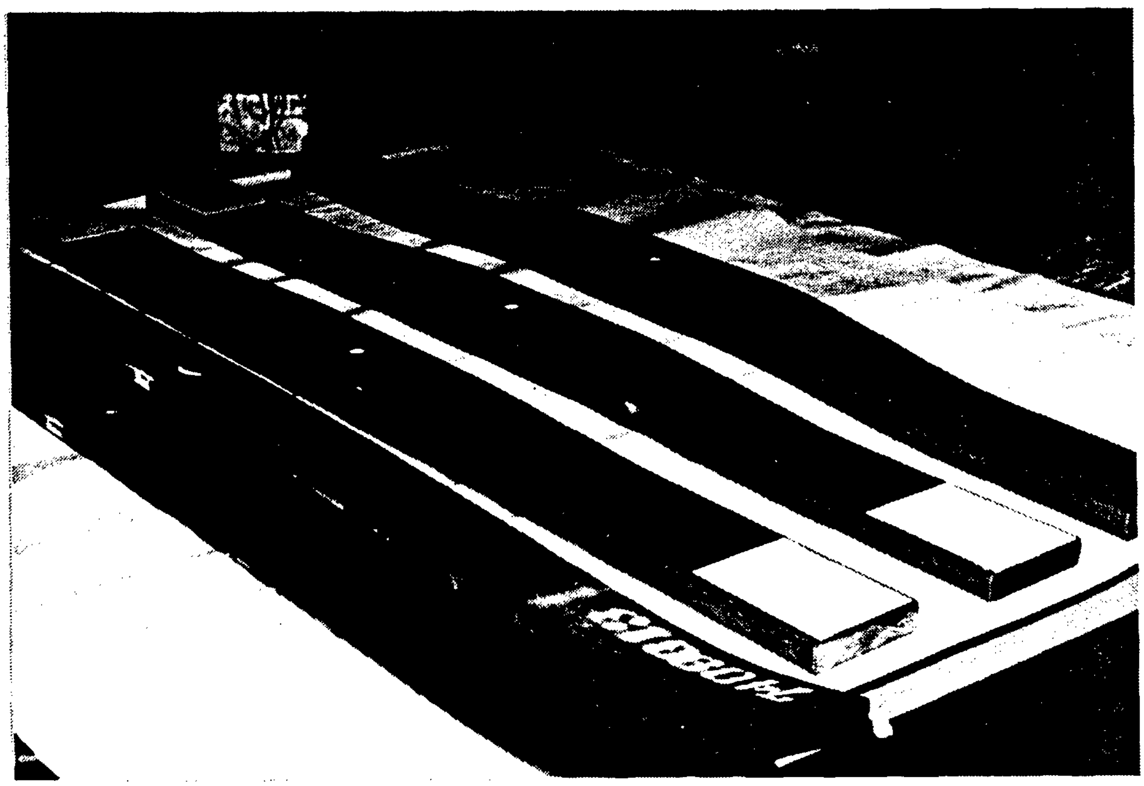
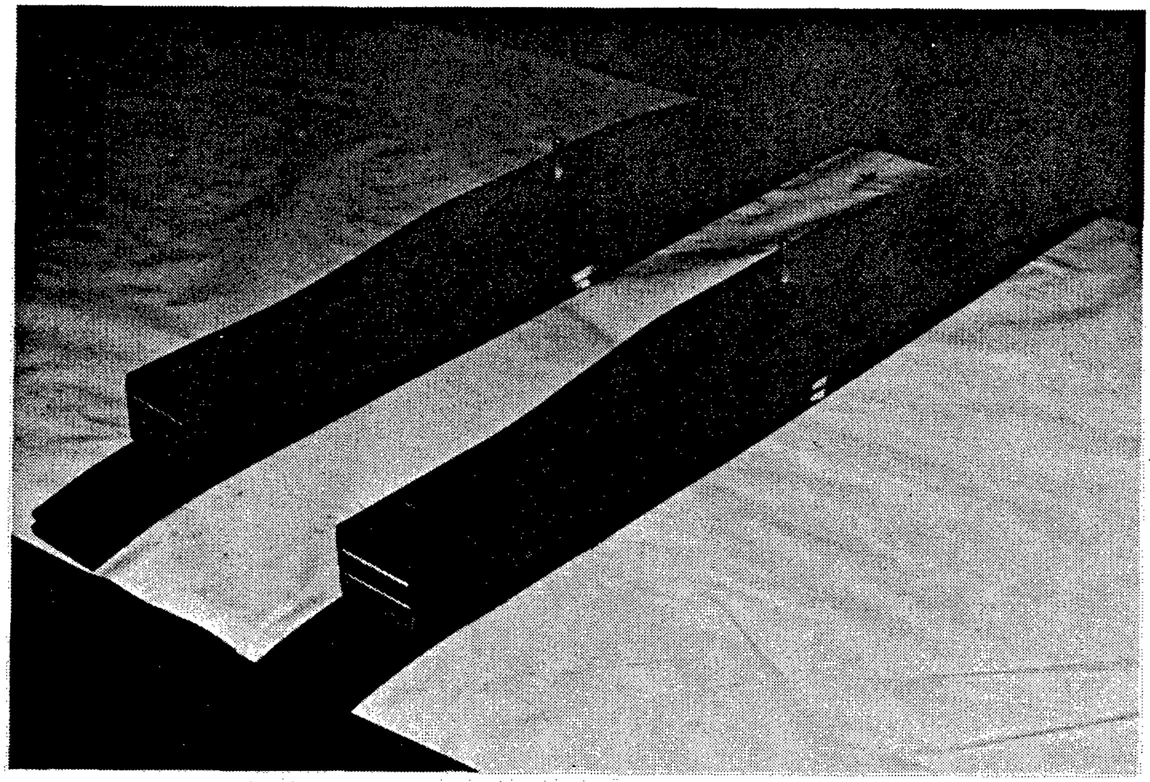


Fig. 6-13. Rear Spring Prior to Assembly



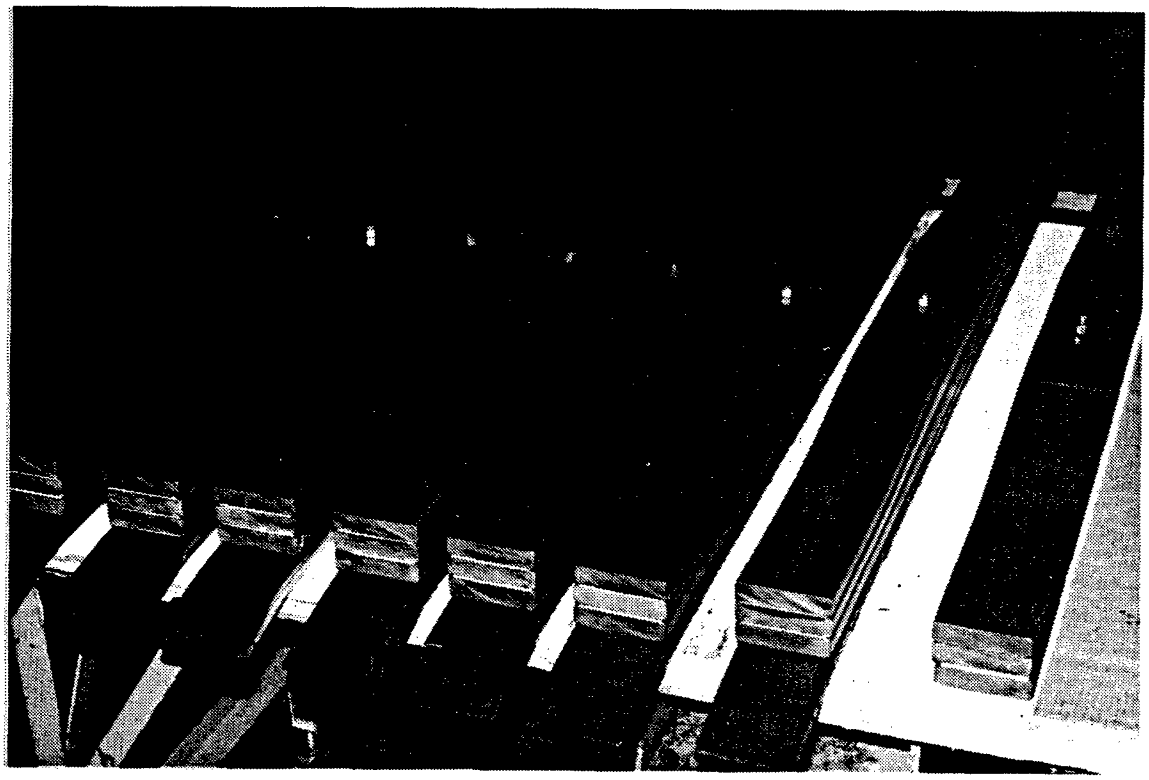


Fig. 6-14. Assembled Rear Spring

6.4 Fabrication - Phase II, Front Spring

6.4.1 Tooling

The two composite leaves in the front spring assembly were fabricated in matched molds made of aluminum. The molds were of a different construction than those used for the rear spring described in paragraph 6.3.1. The slight curvature of the rear spring leaves allowed the mold surfaces to be machined from a solid aluminum plate. The curvatures of the front spring leaves are more pronounced and require a much deeper mold. Machining the mold from a solid aluminum block was not practical because of cost considerations. Instead, the mold was made from one inch thick aluminum plates bolted and joined together to form the required width. Eleven plates were required to make up the mold. The contour was NC machined in each plate. Side plates made of 1/2 inch (13 mm) thick steel were attached to the convex half of the mold. Vertical slots provided indexing and stops for the concave half. The ends of the mold were left open. Figure 6-15 shows the mold design, and Figures 6-16 and 6-17 show details of one of the molds. The molds are wide enough to produce a laminate from which three leaves can be cut.

Some problems were encountered with this mold construction. When pressure was applied to the mold, the plates shifted and spread apart enough to produce visible ridges in the laminate. This condition was rectified by a thin metal caul sheet placed over the contoured mold surface. The molds were not heated internally as were the rear spring molds. Heat was supplied through contact with heated press platens.

6.4.2 Component Fabrication

Cutting and stacking of individual plies was performed in the same manner as described for the rear spring leaves in paragraph 6.3.2. See figure 6-18.

The stacks were debulked under a vacuum and placed on the convex mold surface. A tedlar release cloth separated the laminate from the caul sheet. No bleeder cloth was used. The lay-up was cured at 100 psi (690 KPa) and 250 degrees F. (121 degrees C).

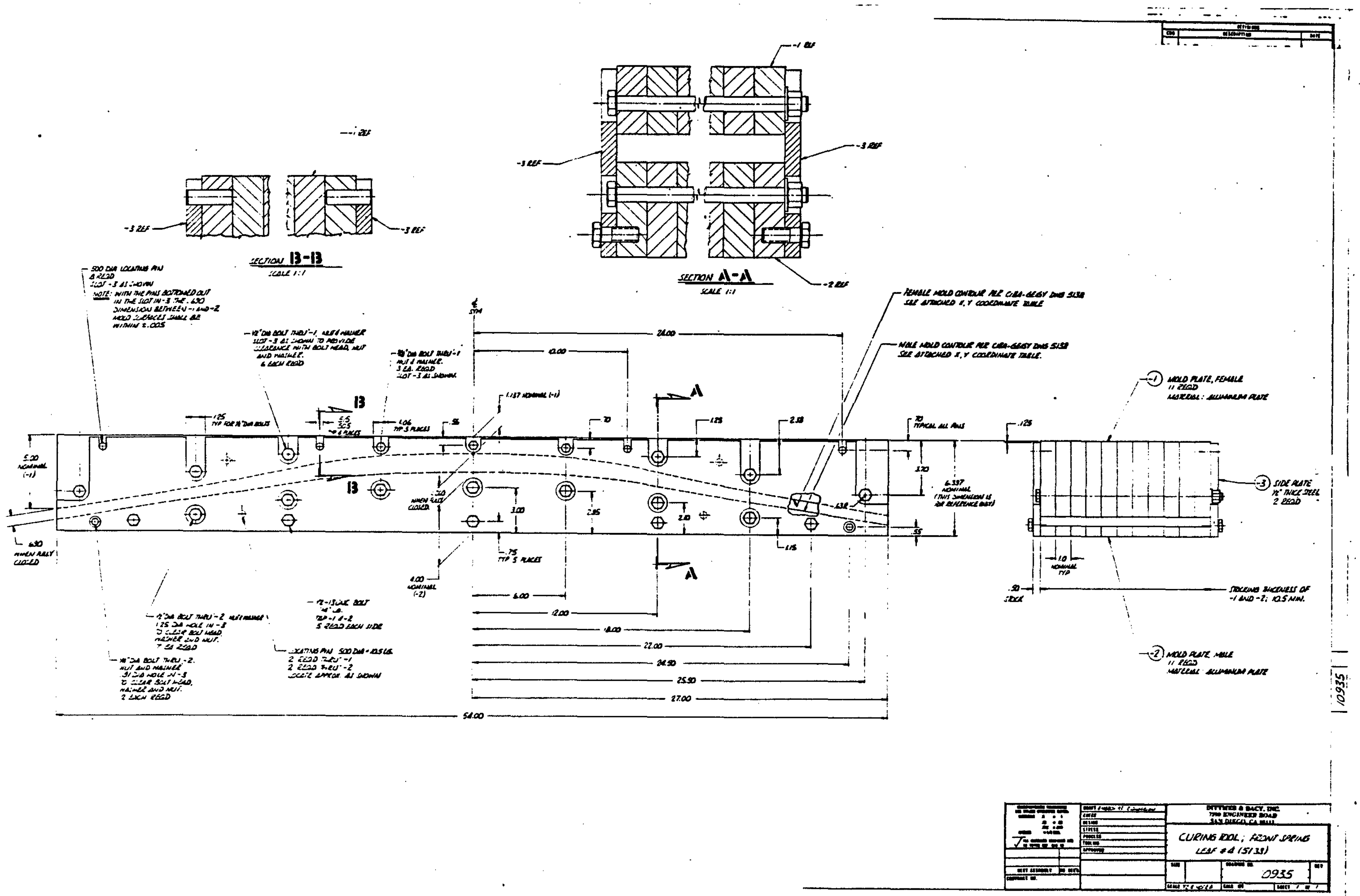


Fig. 6-15. Front Spring Leaf Mold Design

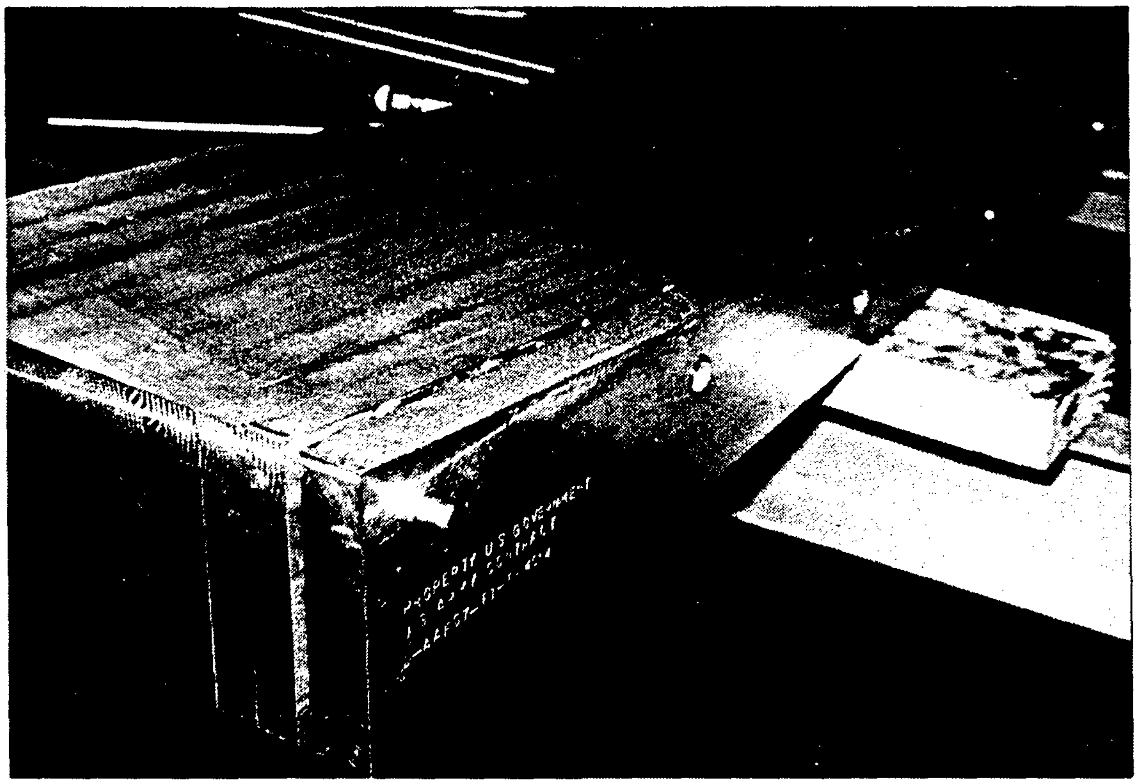


Fig. 6-16. Mold Detail, Front Spring

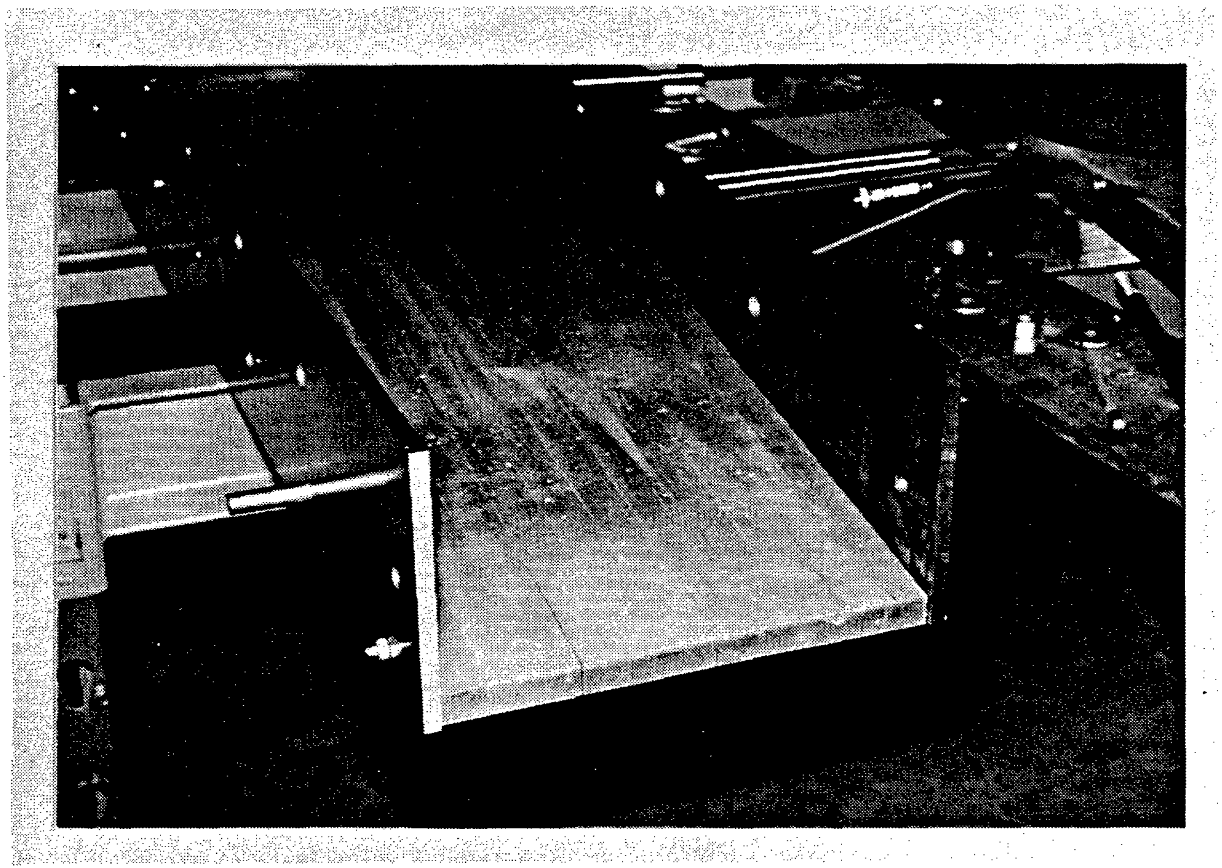


Fig. 6-17 Mold Detail, Front Spring

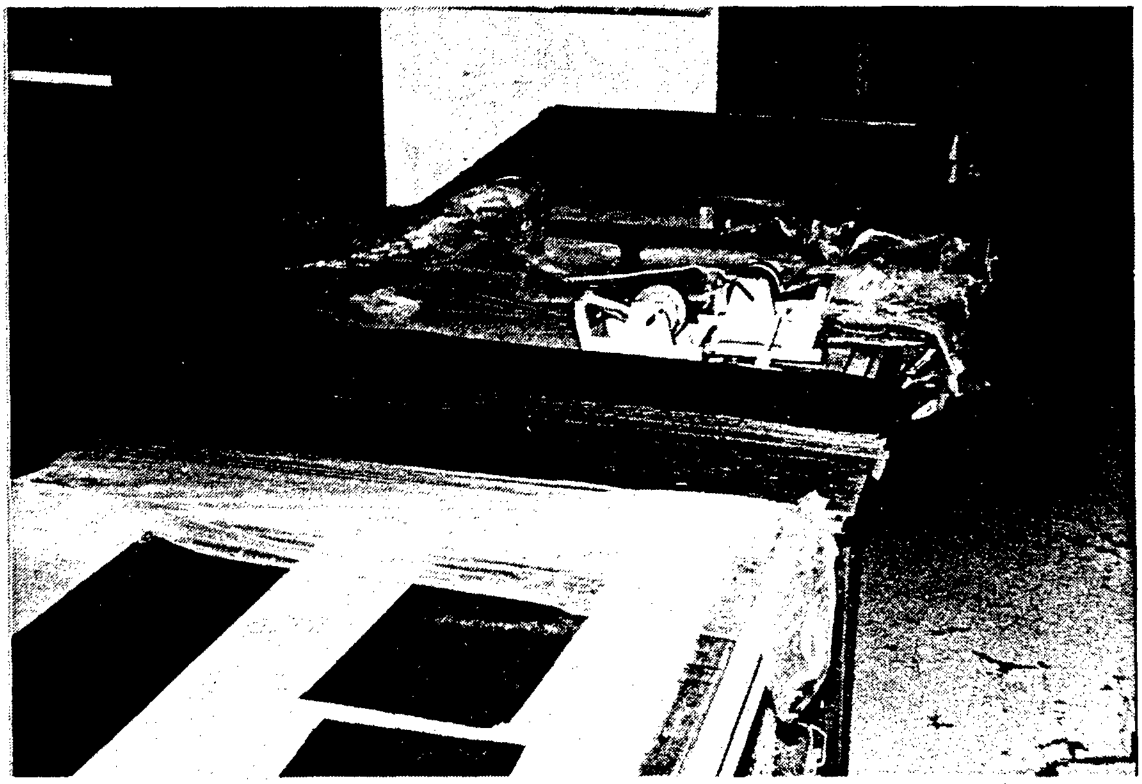


Fig. 6-18 Cutting and Stacking Prepreg

The curing operation for the front spring leaves was different than for the rear spring leaves in that a heated press was used instead of an internally heated mold. The mold, positioned in the press, in shown in Figure 6-19. Not shown in the picture is the insulation blanket covering the exposed surfaces of the mold during the curing operation.

Cutting of individual leaves from a billet and rounding of the edges was performed in the same manner as was described earlier for the rear spring leaves. Figure 6-20 shows the three leaves sliced from one billet. The markings are thickness dimension notations. This set was used to verify the correctness of the mold contours.

Spacers and Teflon wear pads were added to the leaves. After the hole for the center bolt had been drilled, the Teflon pads were masked and the leaves were given a spray coat of polyurethane. A step by step procedure for fabrication of the composite leaves is included in Appendix B. A completed leaf is shown in Figure 6-21. A detail of the center spacer is shown in Figure 6-22, and of the wear pad in Figure 6-23. The fixture for bonding of the wear pad is shown in Figure 6-24.

6.4.3 Assembly

The two composite leaves were assembled to four steel leaves in accordance with the assembly drawing shown in Figure 6-25. The steel leaves were obtained from the existing steel spring assembly, Ordnance Part no. 7411110. Ten of these assemblies were purchased from Rockwell International, Suspension Components Division, Troy, Michigan. No alterations were made to the three top leaves. The bottom leaf, which is leaf number 10 in the steel spring assembly, was machined per the drawing shown in Figure 6-26. The chamfer and radiused corner were added to prevent point contact and stress concentrations in the composite leaf during deflection of the spring. The center bolt in the steel spring assembly was also used in the composite spring. The clamped thickness is approximately the same in both assemblies so no alteration to the bolt length was required.

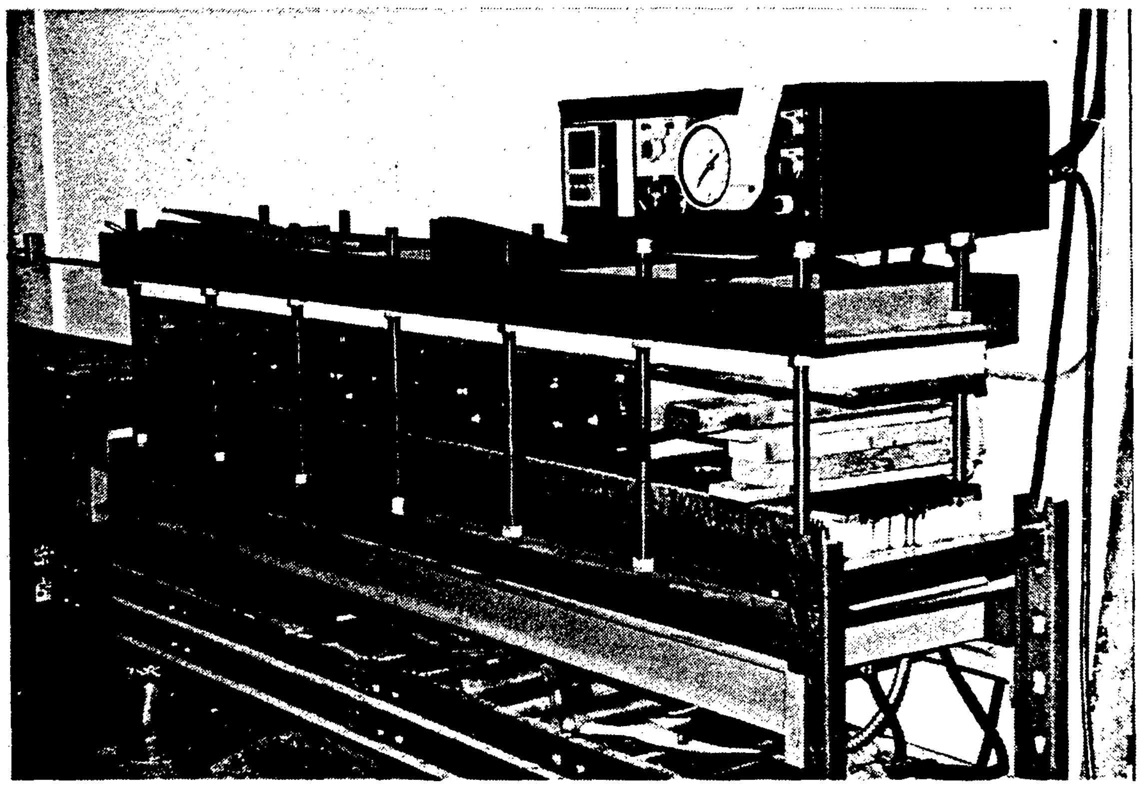


Fig. 6-19. Front Spring Mold Installed in Press

Fig. 6-20. Spring Leaves Sliced from Billet

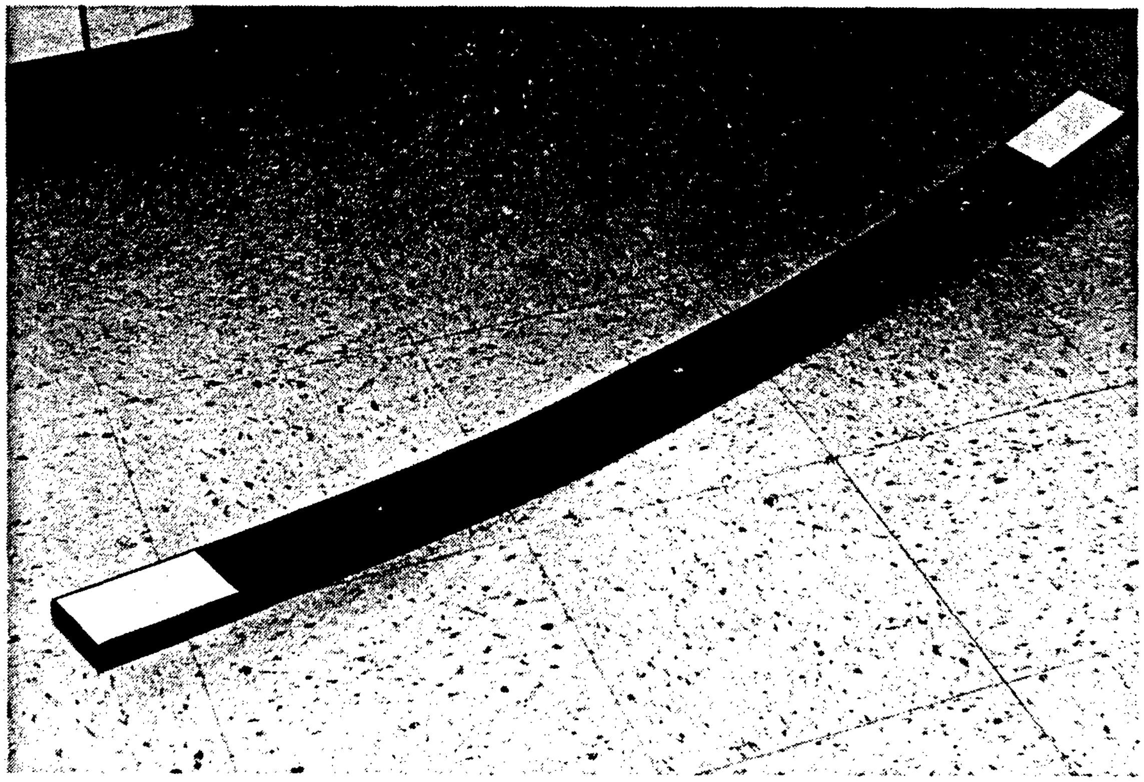


Fig. 6-21. Front Spring Leaf

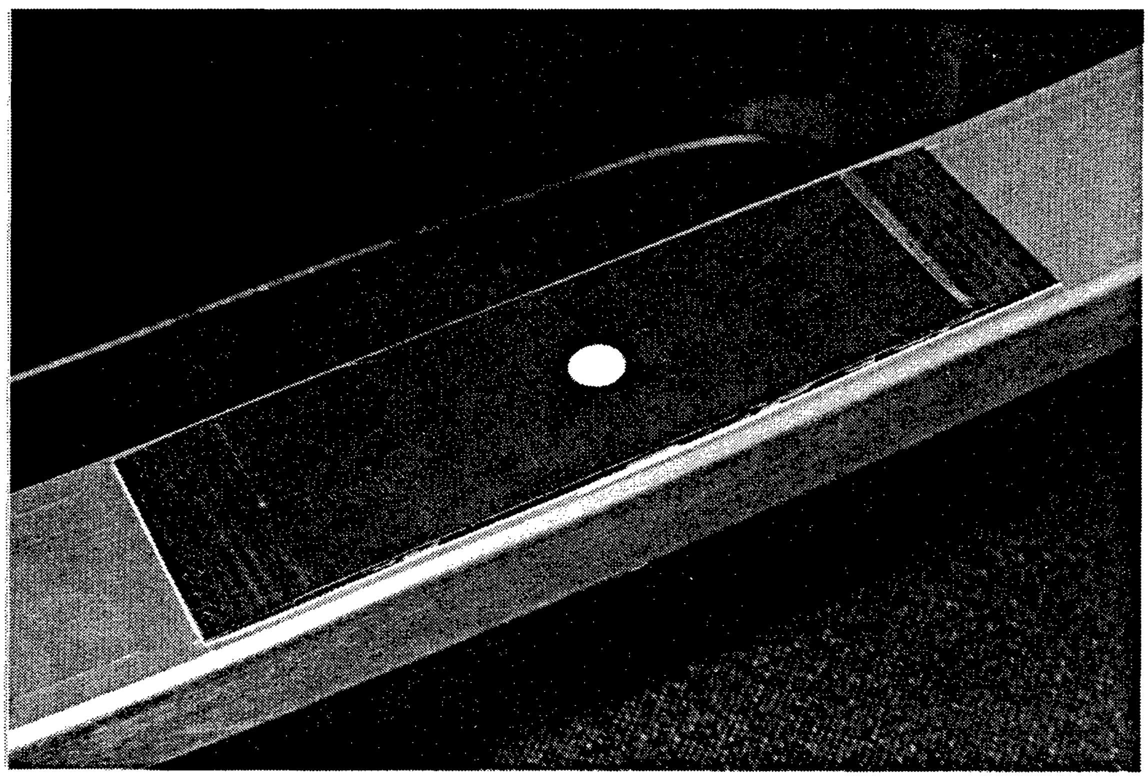


Fig. 6-22. Detail of Spacer

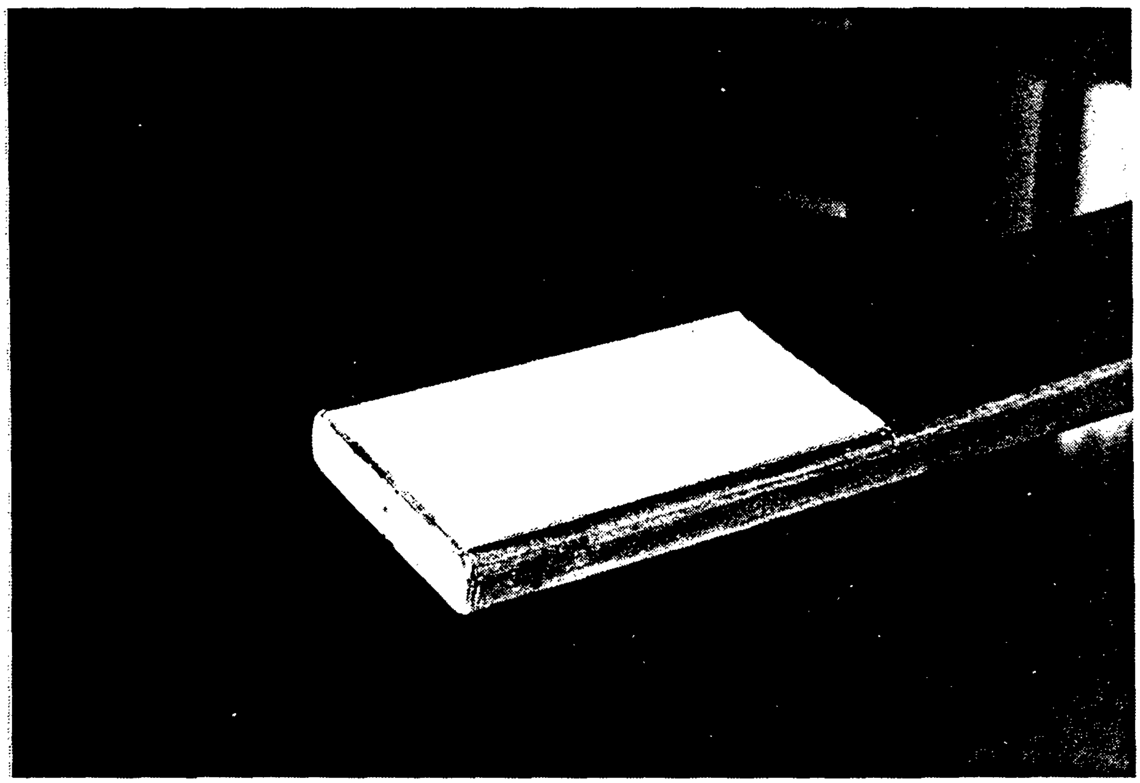


Fig. 6=23. Teflon Wear Pad

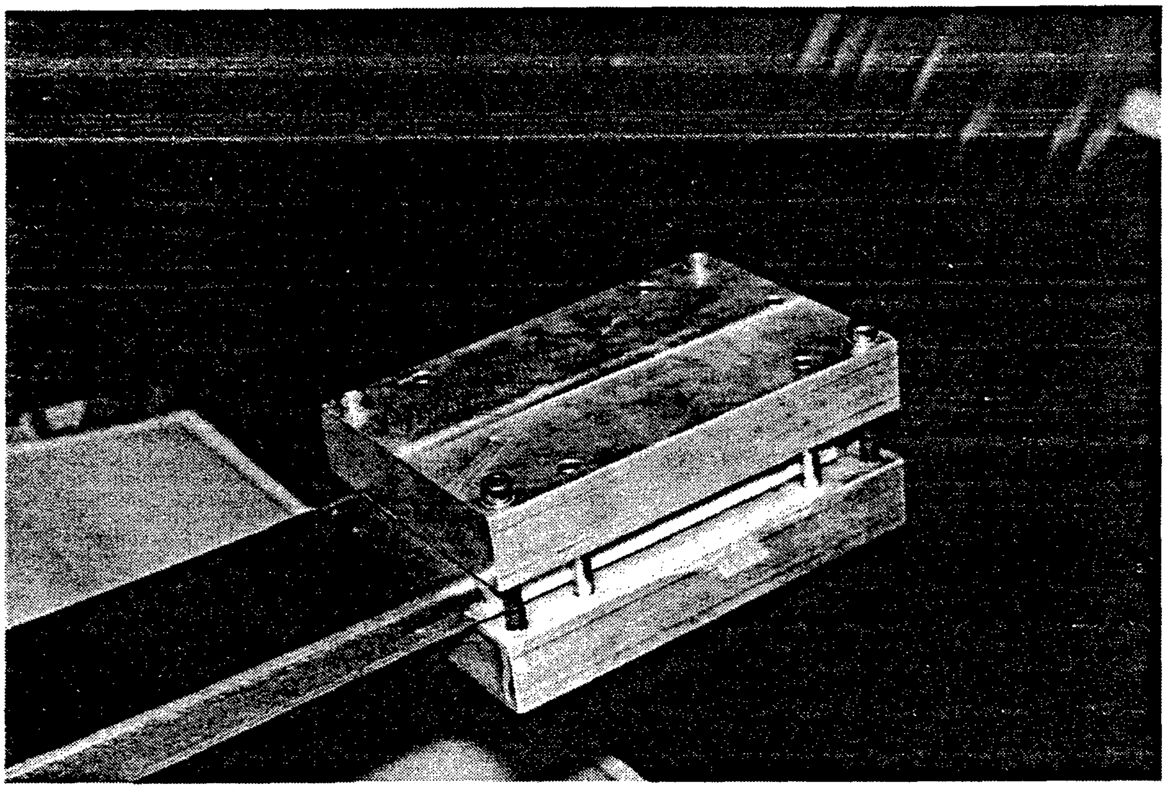


Fig. 6-24. Fixture for Positioning and Bonding of Wear Pad

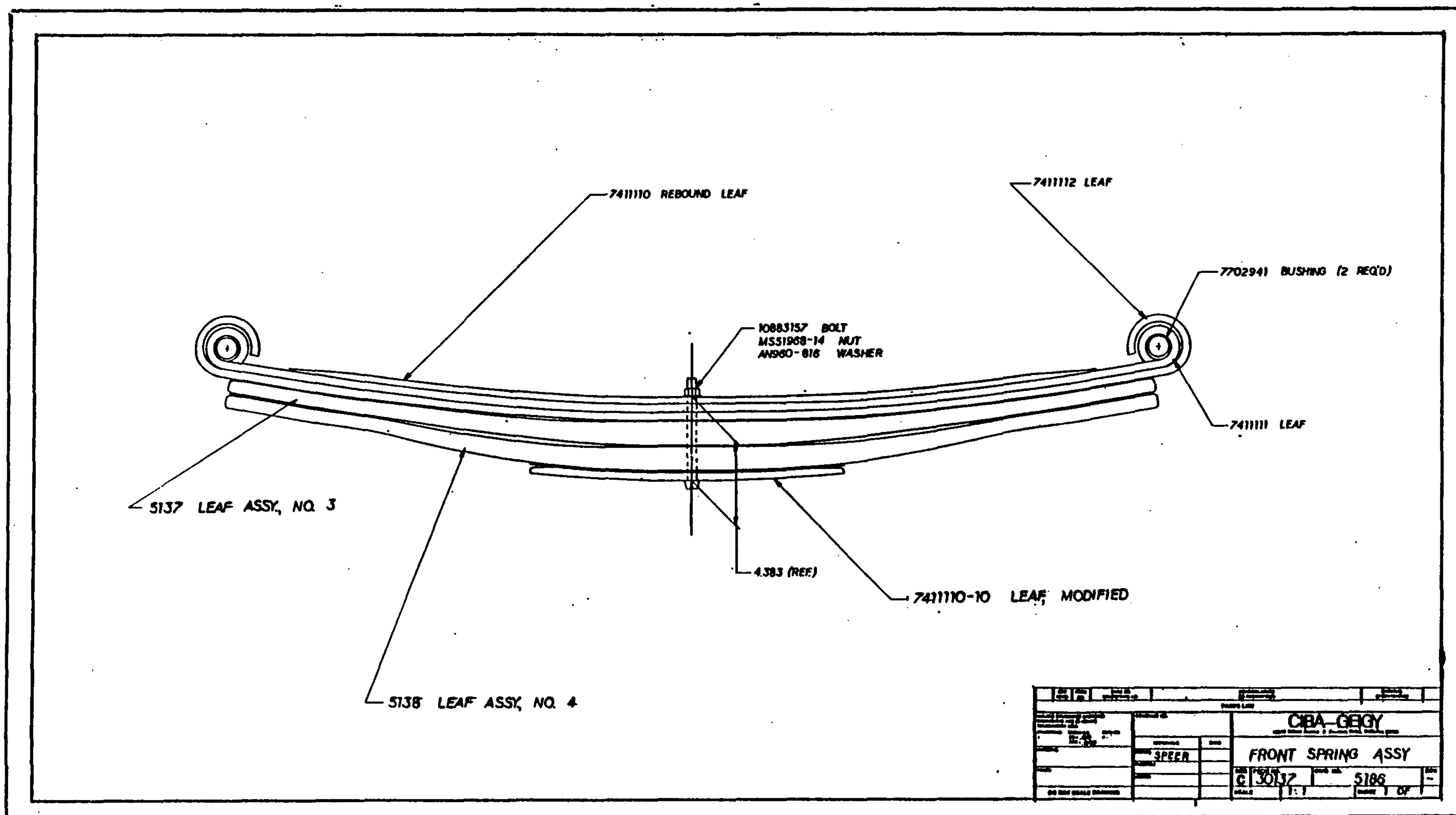


Fig. 6-25. Front Spring Assembly

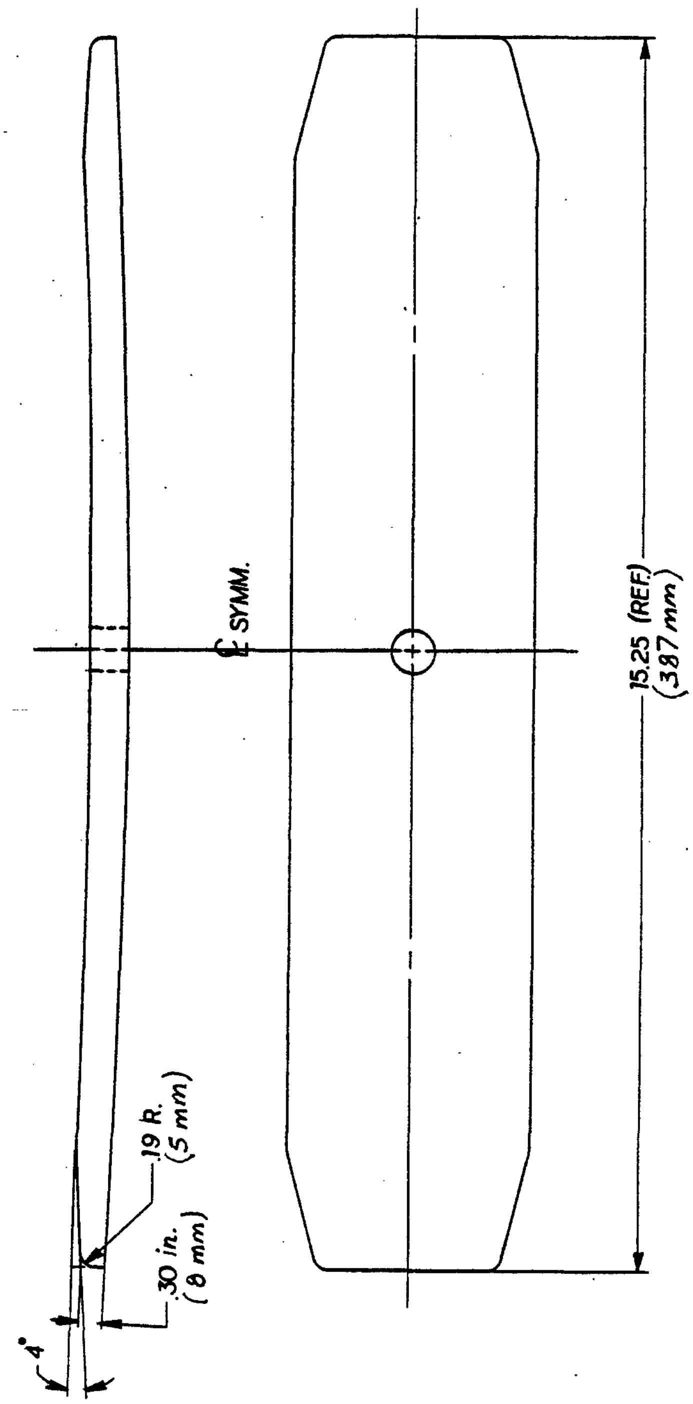


Fig. 6-26. Leaf No. 10 Modification

The clips used to align the leaves in the steel spring assembly were deleted from the composite spring for the same reasons stated for the rear spring in paragraph 6.3.3.

The springs were assembled and shipped to TACOM, Warren, Michigan for testing. The front spring assemblies are shown in Figures 6-27. Details of the assembled spring are shown in Figures 6-28 and 6-29.

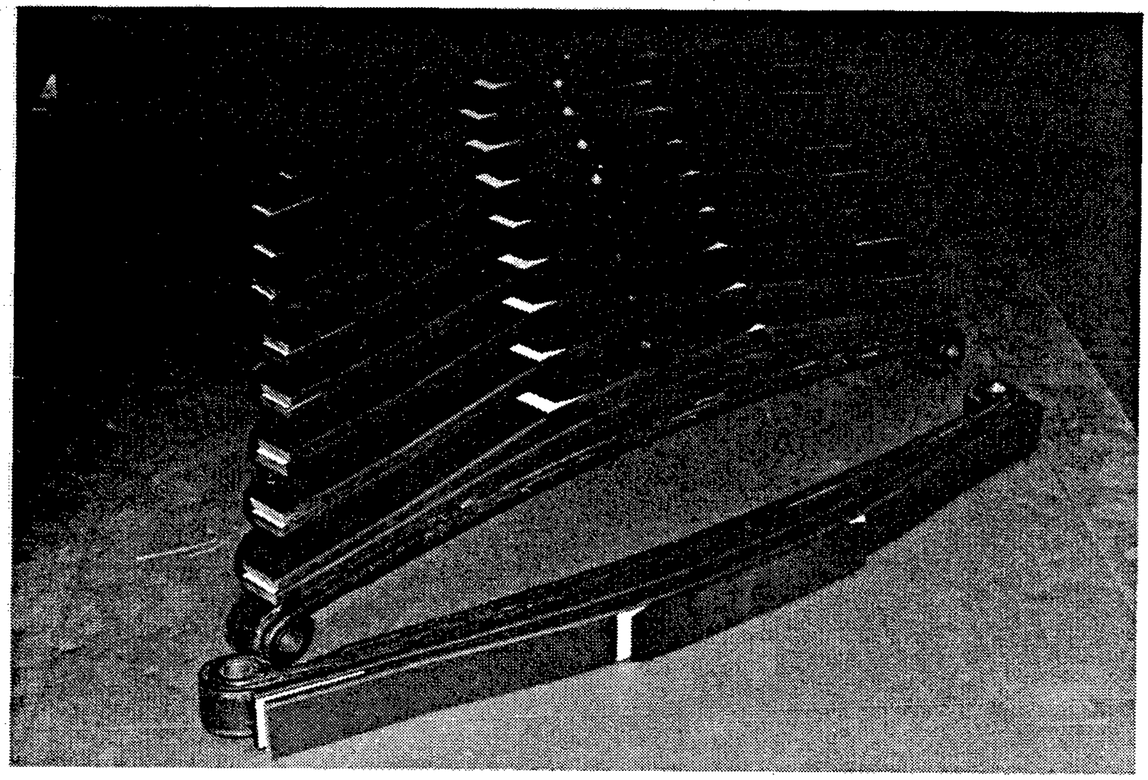


Fig. 6-27. Assembled Front Springs

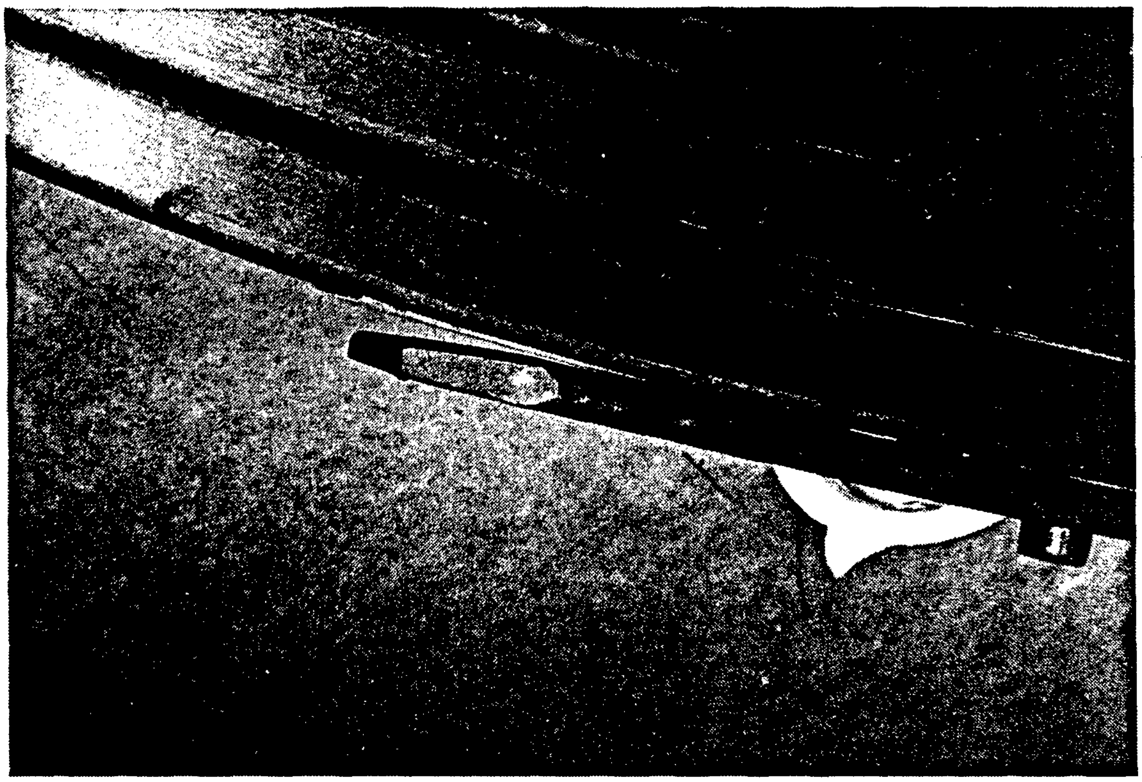


Fig. 6-28 Detail of Lower Leaf

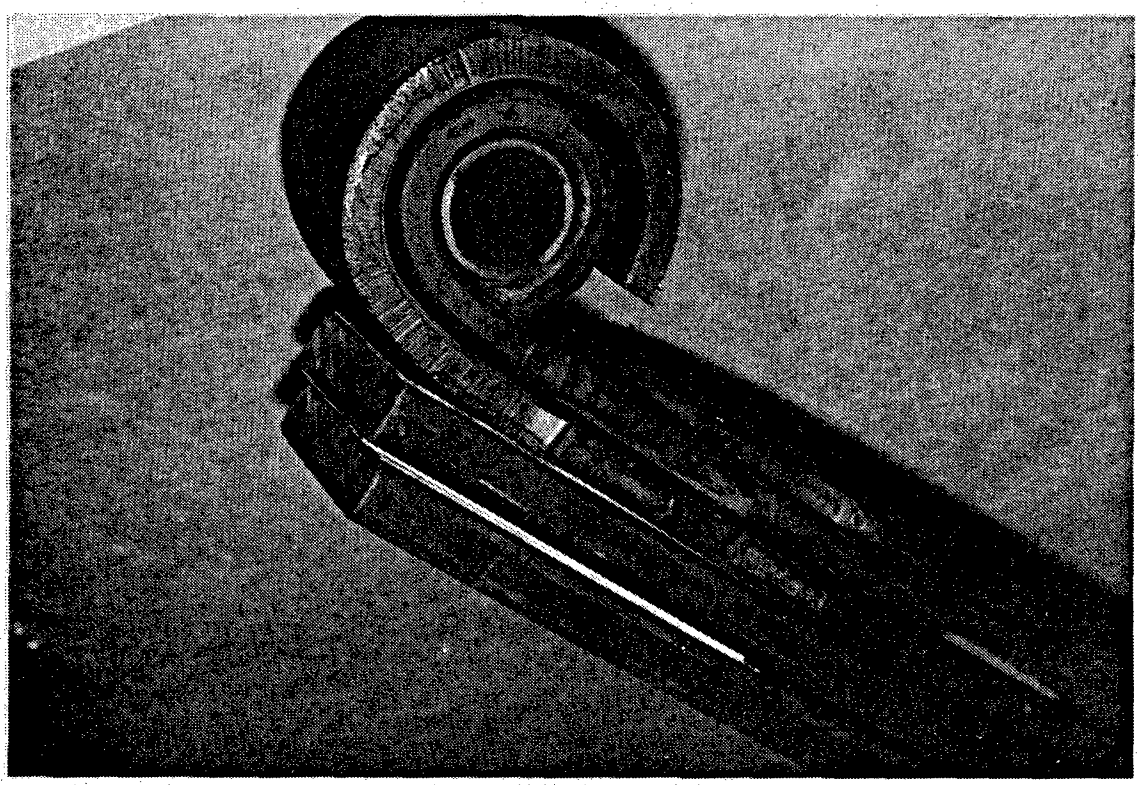


Fig. 6-29. Detail of Mounting Eye

7. Testing of Prototype Spring Leaves

7.1 Introduction

Testing of the spring assemblies was not a contractor responsibility and was to be conducted at TACOM. CIBA-GEIGY, however, decided to include a limited testing program of individual leaves. The purpose of the in-house testing was to assist in the evaluation of the design. The testing consisted of static loading to verify spring rates and fatigue loading. Test specimens were cut from some of the leaves for testing of flexure strength and interlaminar shear strength.

7.2 Test Set-Up

Static and fatigue testing of individual leaves conducted by CIBA-GEIGY was performed in a test fixture specifically designed for testing thin, flat beams in bending. The test set-up is shown in Figure 7-1. The tips of the leaves are clamped to pivoting links which compensate for changes in length during flexure. The load is applied at the center as a point load to represent an unclamped spring leaf. The load is applied downward by a hydraulic cylinder, and is measured by a load cell. A linear variable displacement transducer is used to measure deflection. For fatigue testing, the deflections are controlled by micro limit switches. The load and deflection are displayed on digital meters mounted on an instrument panel in the control room. A load/deflection diagram is obtained from an x,y, plotter and a counter records the number of load cycles applied to the test specimen. A pressure sensing device in the hydraulic system provides automatic shut-off in case of changes in pressure limits which would indicate failure of the test specimen or failure within the test set-up.

7.3 Test Results

When testing individual leaves, the load is applied as a point load at the center of the leaf, whereas in the assembled spring the load is distributed over the area of the clamp. In the assembled spring, the bending stresses at the center of the leaf is, therefore, close to zero, but in the tests the maximum bending stress occur at the center. The deflection for the individual leaf must, therefore, be adjusted so that the bending stress at the center of the leaf does not exceed the calculated value. The center bolt hole was not drilled in the test leaves for that reason.

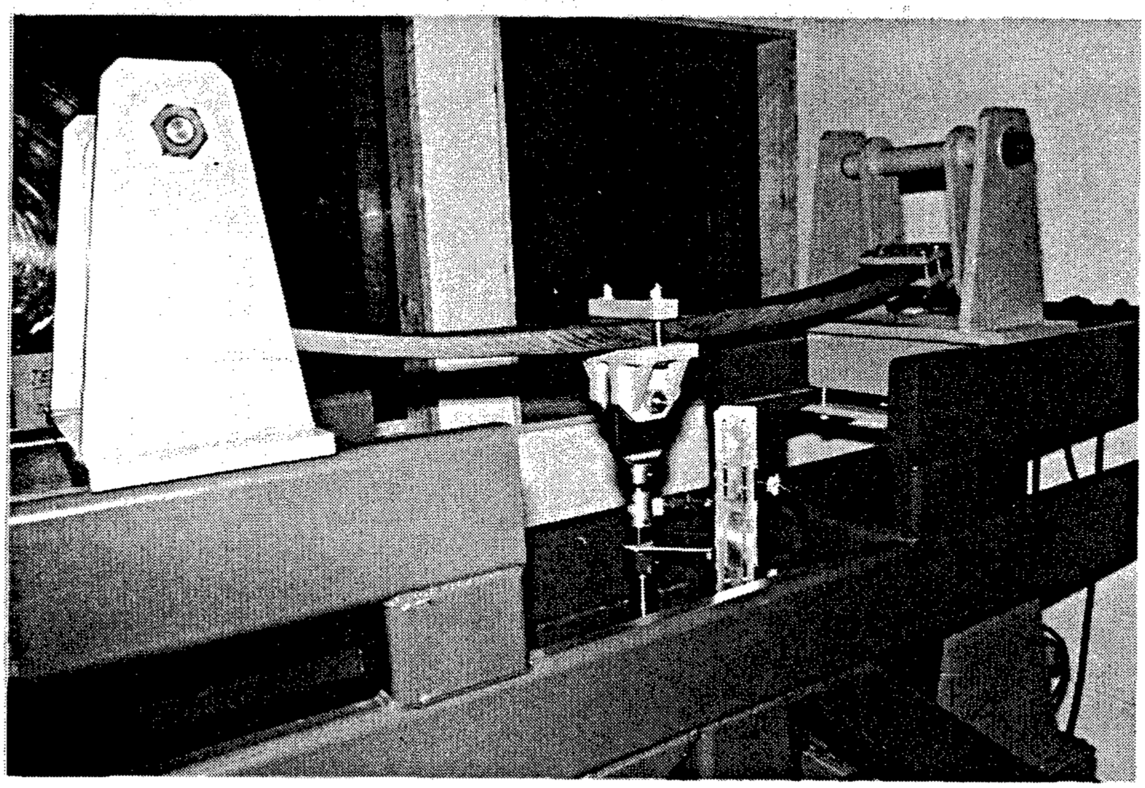


Fig. 7-1 Test Set-up for Fatigue Cycling

From the fatigue load study in Section 3.0, a fatigue life of 30,000 cycles was predicted for a loading ratio of R = .16 (R = min./max. stress) at a maximum bending stress of 116,000 psi (800 MPa). One leaf was tested at this stress level, but at a loading ratio, of R = 0. The expected life of this combination is 10,000 cycles. The test was discontinued after 11,000 cycles because of time limitation. The leaf did not show any signs of degradation. The cycling capacity of the test fixture at this load/deflection was four cycles per minute and it was, therefore, decided to cycle the leaves at higher stress levels and a loading ratio of 0, in order to shorten the testing time. Three more leaves were tested at stress levels of 121 ksi, 118.5 ksi and 117 ksi (834, 817, and 807 MPa). All leaves failed at less than the predicted number of cycles. The fatigue life was predicted from the Goodman diagram for S2-glass fiber/epoxy shown in Figure 3-3 in Section 3.0. Assuming that the Goodman diagram reflects realistic numbers, the test results of the three leaves indicate that the ultimate flexure strength was 160 to 165 ksi (1103 to 1138 MPa), instead of 185 ksi (1276 MPa) as used in the design calculations. The probable reason for this is that these leaves were made from a prepreg batch which has lower than nominal resin content, although still within the specified limits. Coupon testing also indicated lower flexure strength for laminates made from low resin content prepreg. A typical leaf failure is shown in Figure 7-2.

As a result of the testing, prepreg rolls with higher than nominal resin content were selected for fabricating the leaves used in the delivered spring assemblies. Time did not permit testing of these leaves.

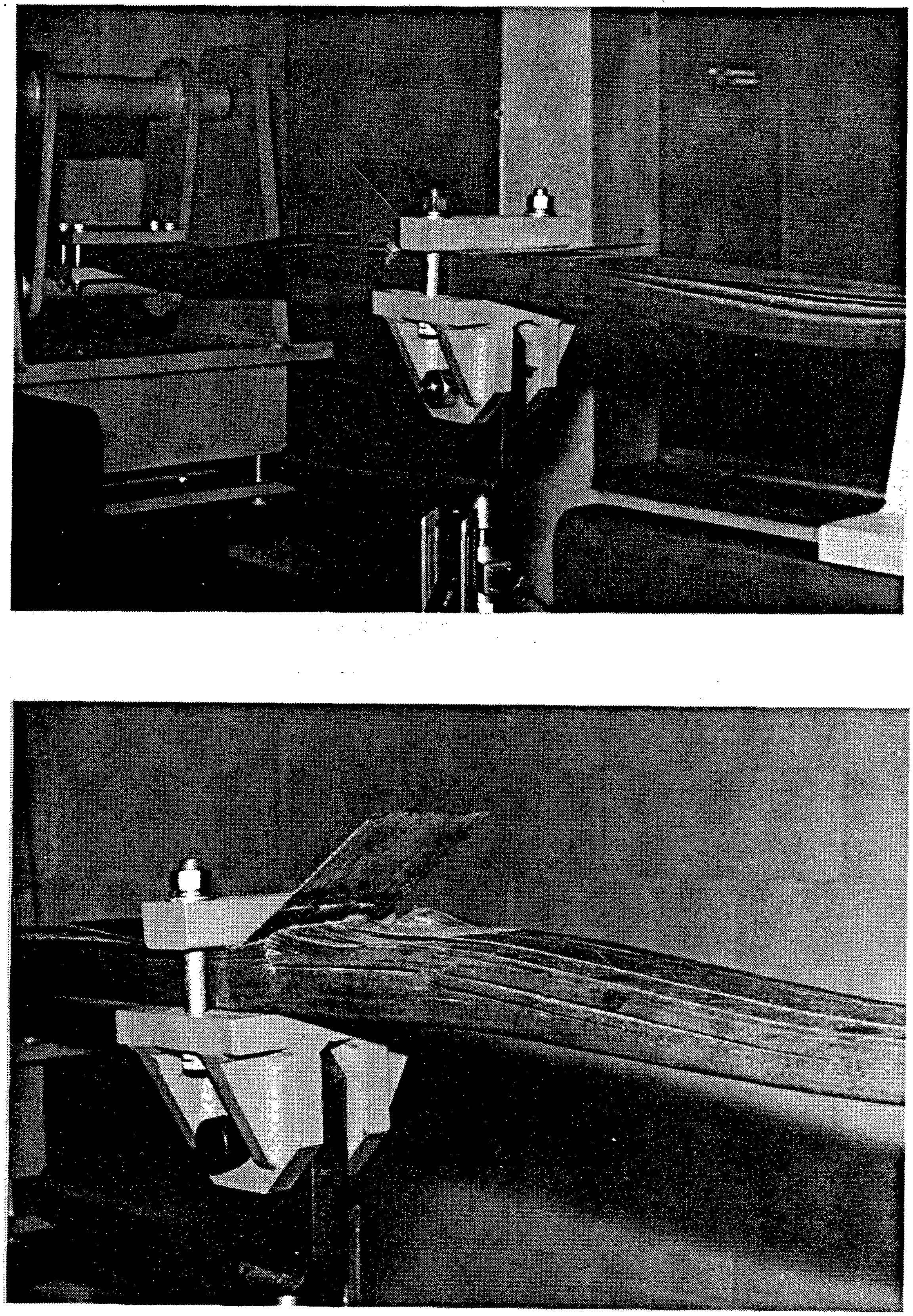


Fig. 7-2. Typical Fatigue Failure of Rear Spring Leaf

8. Economic Analysis

8.1 Introduction

An economic analysis was performed for quantity production of composite leaf springs using the manufacturing process described in paragraph 6.2. The following quantities were used in the analysis:

Yearly Quantity	Production Rate
1,200 each*	100 per month
5,100 each	425 per month
10,200 each	850 per month

*Front spring assembly and rear spring assembly

All costs are expressed in FY80 dollars and are based on one shift, eight hours per day, and five days per week (1-8-5).

All research and development costs are considered sunk and have not been included in the analysis. The costs have been divided into the following elements:

Non-Recurring Costs

Initial production facilities

Production Costs

- Manufacturing costs
- Engineering costs
- Sustaining tooling costs
- Quality control costs

8.2 Non-Recurring Costs

A detailed breakdown of the non-recurring cost elements for the three production rates is shown below.

8.2.1 Initial Production Facilities

	Cost, K$ (FY8Ø)		
Units* Per Year:	1,2ØØ	5,1ØØ	1Ø,2ØØ
Tooling and Equipment			
1. Prepreg handling and storage racks	1Ø	4Ø	5Ø
2. Prepreg cutting and stacking (modified Century Design Model M-51ØØ)	5Ø	5Ø	5Ø
3. Debulking Molds			
Rear Spring, 3 req'd @ 3K	9	9	9
Front Spring, 2 req'd @ 3K	6	6	6
4. Rf Staging Equipment	25	25	25
5. Misc. Handtools, Work Tables, Carts, etc.	5	12	24
6. Compression Molds (produces 1Ø leaves per operation)			
Rear Spring, 3 req'd @ 6ØK	18Ø	18Ø	18Ø
Front Spring, 2 req'd @ 55K	11Ø	11Ø	11Ø
7. Mold Handling Equipment (Die Truck and Storage Racks)	25	25	25
8. Press, 2ØØ ton @ 3ØØ K	3ØØ	3ØØ	6ØØ
9. Heating Source for Press @ 2ØØK	2ØØ	2ØØ	2ØØ
1Ø. Restraining Fixture for Cool Down of Laminate @ .5K			
Rear Spring	3	12	24
Front Spring	2	8	16
11. Automated Equipment for Cutting Billets and Routing Leaves	15	12Ø	24Ø
12. Cutting and Shaping Tool for Spaces and Pads	1Ø	25	25
13. Bonding and Drilling Fixtures	5	18	36
14. Adhesive Mixing Facilities	-	3	3

8.2.1 Initial Production Facilities (con't.)

	Cost, K$ (FY80)		
Units* Per Year:	1,200	5,100	10,200
Tooling and Equipment			
15. Spray Paint Booth and Heat Curing	25	35	35
16. Q.C. Equipment, Measuring Tools and Fixture	6	20	20
17. Test Fixture for Measuring Spring Rate	10	10	10
18. Assembly and Installation of Tools and Fixture			
19. Plant Engineering, Preparation for Production, Operations Check Out, N.C. Computer Tapes, etc.	90	200	280

* One unit is one front spring assembly and one rear spring assembly.

8.2.2 Plant Facilities

Plant 7500, 20,000, 25,000 sq. ft. (697, 1858, 2323 sq. meter)	225	600	750
Total Non-Recurring Costs	1,311	2,008	2,718

8.3 Production Costs

Production costs have been based on the following:

Direct Labor Charges
Labor Overhead, 150%
Material Charges
Material Handling Overhead, 10%
General and Administrative expenses, 15%
Profit/Fee, 8%

Burdened Labor Rate, dollars/hour

Fabrication	23.75
Inspection	23.75
Engineering	39.50

Burdened Material Costs	dollars/pound	$/kg
Fiberglass prepreg (S-2)	8.00	17.64
Steel (as fabricated)	.70	1.54

Costs to manufacture the 500th unit was estimated.

8.3.1 Rear Spring

Fabrication of Leaves	4.95	mhr	@ 23.75
Assembly and Packaging	.80	"	@ 23.75
Inspection and Testing	.35	"	@ 23.75
Production Engineering	.35	"	@ 39.50

Burdened Labor Cost for 500th unit, $159.00

Using a 90% learning curve the cost of the first unit is $296.00. Figure 8-1 shows the learning curve for the rear spring assembly.

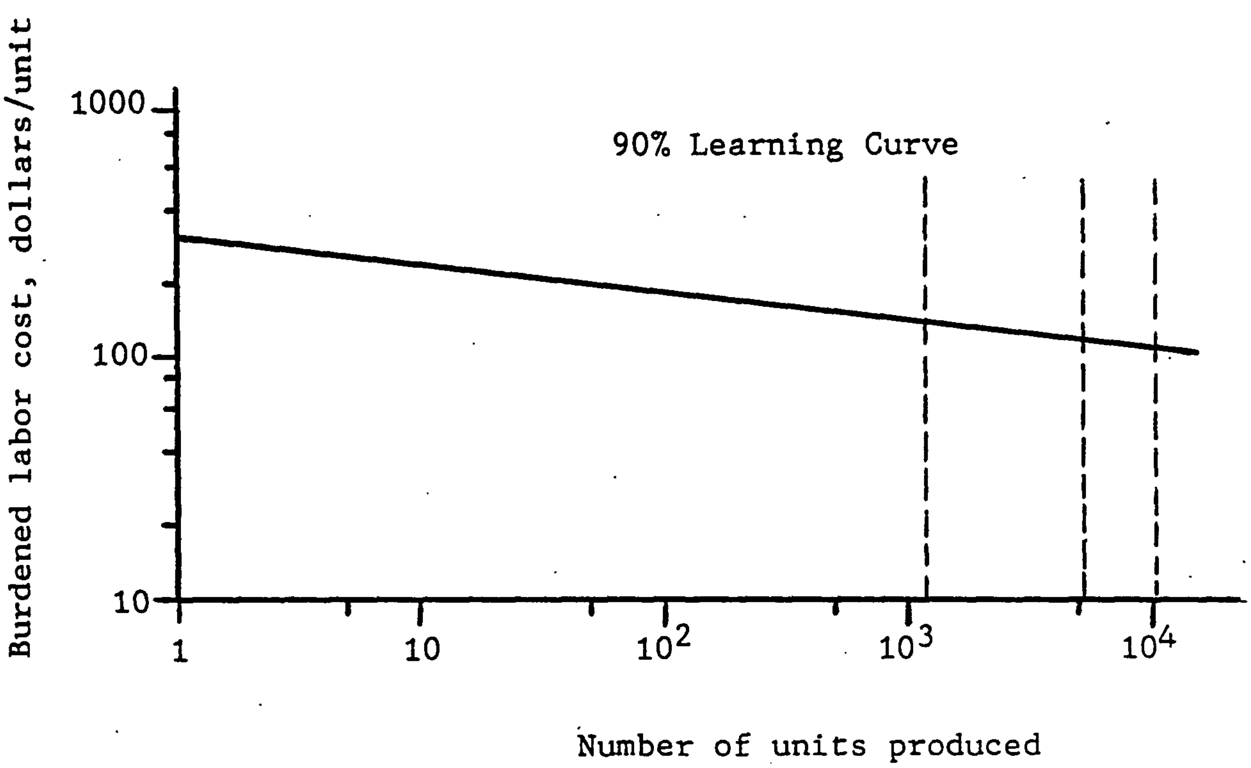


Fig. 8-1. Learning Curve for Composite Rear Spring

Sustaining Tooling Costs, Rear Spring

		Cost, K$ (FY80)	
Units Per Year:	1,200	5,100	10,200
1. Tooling Maintenance	9	12	15
2. Replacement of Tooling (cutting tools)	12	50	100
3. Modification of Tooling	8	25	45
TOTAL	29	87	160
Costs per unit, $	24	17	16

Manufacturing costs to produce the 1,200th, 5,100th and 10,200th rear spring assembly is shown below. Non-recurring costs are not included.

		Cost, $ (FY80)	
Unit Number	1,200	5,100	10,200
Summary, Rear Spring			
Burdened Labor	142	122	113
Material			
Prepreg, 56 lbs @ $8.00 (includes 20% scrap)	448	448	448
Spacers, pads, adhesive	27	27	27
Steel parts	70	70	70
Shipping Costs	21	21	21
Sustaining Tooling Costs	24	17	16
TOTAL	732	705	695
Selling Cost	909	876	863

8.3.2 Front Spring

Fabrication of Leaves	3.30 mhr	@ 23.75
Assembly and Packaging	.75 "	@ 23.75
Inspection and Testing	.30 "	@ 23.75
Production Engineering	.30 "	@ 39.50

Burdened labor cost for the first unit is $214. Fig. 8-2 shows the learning curve for the front spring assembly.

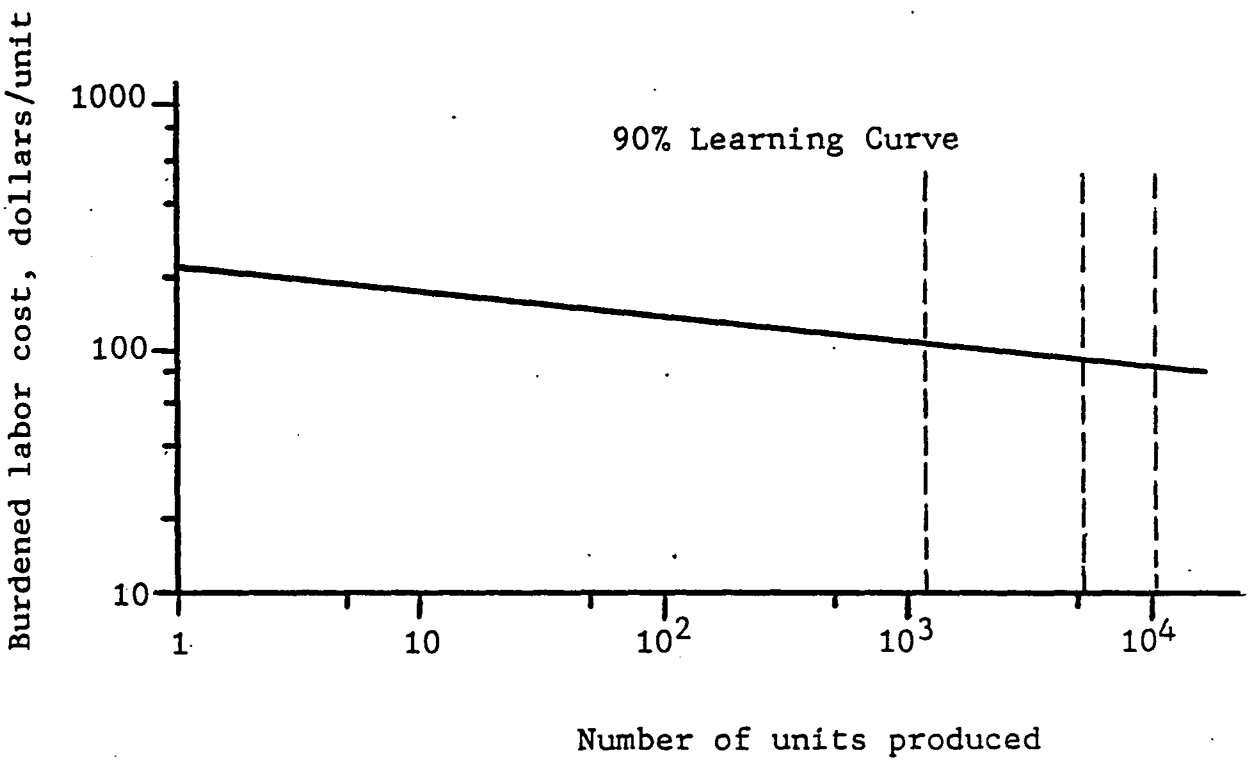


Fig 8-2. Learning Curve for Composite Front Spring

Sustaining Tooling Costs, Front Spring

	Cost, K$ (FY8Ø)		
Units per Year	1,2ØØ	5,1ØØ	1Ø,2ØØ
1. Tooling Maintenance	6	8	1Ø
2. Replacement of Tooling (cutting tools)	8	34	68
3. Modification of Tooling	5	17	3Ø
TOTAL	19	59	1Ø8
Cost per Unit, $	16	12	11

Manufacturing costs to produce the 1,2ØØth, 5,1ØØth and 1Ø,2ØØth front spring assembly is shown below. Non-recurring costs are not included.

	Cost, $ (FY8Ø)		
Unit Number:	1,2ØØ	5,1ØØ	1Ø,2ØØ
Summary, Front Spring			
Burdened Labor	1Ø6	93	87
Material			
Prepreg, 26 lbs. @ $8.ØØ (includes 2Ø% scrap)	2Ø8	2Ø8	2Ø8
Spacers, pads, adhesive	16	16	16
Steel Parts	33	33	33
Shipping Costs	14	14	14
Sustaining Tooling Costs	16	12	11
TOTAL	393	376	369
Selling Cost	488	467	458

8.4 Economic Analysis Summary

From the preceding analysis it is apparent that the cost to manufacture composite leaf springs is material rather than labor intensive. Therefore the difference in unit cost for the production rates of 1,200, 5,100 and 10,200 units per year is relatively small.

For a largely automated manufacturing process the cost of tooling and equipment becomes very high. The non-recurring costs itemized in paragraph 8.2.1 and amortized over one year show the unit costs to be $1093, $394 and $266 for 1,200, 5,100 and 10,200 units respectively.

From this it appears that the minimum economical yearly production quantity would be around 5000 units with a monthly production rate of 410 to 420 units.

9. Conclusions and Recommendations

The results of the program show that the selected manufacturing process is suitable for producing heavy duty composite material leaf springs in modest quantities. A large mold, producing wide billets from which several leaves can be cut, is more economical than a single leaf mold, provided that proper equipment for handling the heavier mold is available.

Leaves made of S2-glass fiber and designed with a tapered thickness to produce a constant bending stress along the length of the leaf are necessary to meet the performance requirements.

Testing of the rear spring assemblies by TACOM revealed a stress concentration problem at the center clamp. This problem was solved for the front spring by the addition of a short steel leaf between the lower composite leaf and the center clamp.

The arrangement is described in paragraph 6.4.3. A similar arrangement is recommended for the rear spring. A suitable steel leaf to add to the composite spring assembly is leaf number 12 in the current steel spring assembly, Ordnance Drawing number 7409613. This leaf is 17.3 inches (439 mm) long and would protrude 3.3 inches (84 mm) on either side of the center clamp. The ends of the leaf should be modified similar to the front spring leaf shown on figure 6.26.

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APPENDIX A

FABRICATION PROCESS SHEETS

REAR SPRING ASSEMBLY

SHOP ORDER

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Rear Spring, Leaf #3	5127-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs.; Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		Set up mold in press. Check all heater rod connections. Make sure							
2			all equipment is functioning properly.							
2										
2	02		Clean mold with MEK. Allow to dry for 5 minutes. Spray mold with							
2			Frekote 33 and heat mold to 250 degrees F (121 degrees °C) and bake							
2			for 1 hour, cool. Repeat process two more times.							
2										
2	03		Remove R7269-S2 prepreg from cold storage. Verify acceptance and							
2			shelf life. Record roll and batch numbers. Let stand for 30 minutes							
2			at room temperature.							
2										
2	04		Place prepreg roll on cutting table. Be sure cutting table is clean.							
2										
2	05		Cut prepreg plies per engineering drawing (see attached sheet). Width							
2			of plies should be cut ¼" (6 mm) less than the width of the mold							
2			cavity. Cut patterns so that the fibers are parallel to the sides.							
2										

10-084-123 (REV. 12-64)

SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	06		Stack plies numbers 1 through 54 and place on the debulking tool.							
2										
2	07		Cover with vacuum bag material and seal to tool with sealing tape.							
2			Attach vacuum port and hose. Apply vacuum (25 mm. Hg min.). Hold							
2			vacuum for 3.5 hours at room temperature.							
2										
2	08		Remove vacuum bag and resume layup of plies numbers 55 through 96.							
2			This layup provides the tapered thickness of the leaf. Make sure that							
2			all patterns are centered in the debulking tool and that the step							
2			between each pattern is of the same length on either side of the							
2			center line. To prevent wrinkling of fibers in the curved contour of							
2			the layup, do not stack more than 10 plies (flat pattern) at a time							
2			in the debulking tool.							
2										
2	09		Cover with vacuum bag material and seal to tool with sealing tape.							
2			Repeat step 07.							
2										
2	10		Remove vacuum bag and resume layup of plies numbers 97 through 150.							
2			To prevent wrinkling of fibers, do not stack more than 10 plies (flat							
2			pattern) at a time on the curved contour of the layup in the debulking							
2			tool.							

10-084-124 (REV. 12-64)

SHOP ORDER CONTINUATION SHEET

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	11		Cover layup with vacuum bag material and seal to tool with sealing							
2			tape. Repeat step 07.							
2										
2			*Note: If step 06 is performed at the start of the shift steps 06							
2			through 11 can be completed in one day. Vacuum in step 11							
2			can then be left on over night.							
2										
2	12		Remove vacuum bag. Remove layup from debulking tool.							
2										
2	13		Weigh layup. Record weight. This is a check that the layup contains							
2			the correct number of plies.							
2										
2	14		Cut a piece of .010 inch (.25 mm) thick #7109 Teflon coated fabric of							
2			the same size as the mold cavity. Place the female half of mold. Make							
2			sure that both mold surface and Teflon sheet are clean and free from							
2			foreign particles which may disturb the laminate surface.							
2										
2	15		Preheat mold to 180 degrees F (82 degrees C).							
2										
2	16		Place layup in the female half of the mold.							
2										

10-084-124 (REV. 12-64)

SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	17		Close mold. Apply 100 psig pressure (690 Kpa). Hold for 40 minutes							
2			@ 180 degrees f (82 degrees C). Increase temperature to 205 degrees							
2			F (96 degrees C). Hold for 15 minutes. Increase temperature to 230							
2			degrees F (110 degrees C). Hold for 15 minutes. Increase temperature							
2			to 255 degrees F (124 degrees C). Hold for 15 minutes. Increase							
2			temperature to 280 degrees F (138 degrees C). Hold for 3 hours.							
2			Observe mold. Make sure mold closes properly.							
2										
2	18		Let mold cool to near room temperature while maintaining pressure.							
2										
2	19		Remove laminate from tool.							
2										
2	20		Transfer part to machine shop.							
2										
2	21		Determine center line of laminate and mark with light color marking							
2			pencil across the width of the laminate. Do not use tool with sharp							
2			point to scribe center line.							
2										
2	22		Cut leaves per engineering drawing dimensions from laminate. Use							
2			diamond coated circular saw.							
2										

10-084-124 (REV. 12-64)

SHOP ORDER CONTINUATION SHEET

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	23		Visually inspect cut surfaces for voids and flaws.							
2										
2	24		On accepted parts machine radius along all edges as called out on							
2			drawing.							
2										
2	25		Cut spacers and Teflon rubbing pads per drawing dimensions.							
2										
2	26		Bond spacers and pads to leaf.							
2			Bonding procedure:							
2			Etch surfaces to be bonded with TETRA-ETCH (manufactured by W. L.							
2			Gore and Associates, Flagstaff, AZ, Phone (602)526-1290). Follow							
2			instructions on container. Clean off etchant with detergent							
2			mixture or alcohol.							
2	26		Apply adhesive, Scotch Weld 2216 (3M), to both surfaces. Use locating							
2			tool for bonding (Teflon pads move around when pressure is applied.)							
2			Apply pressure and let stand for ½ hour at 175 degrees F (79 degrees C),							
2			or for several hours at room temperature. Wipe off excess adhesive.							
2										
2	27		Drill .53 inch (13.5 mm) diameter hole at center of leaf per drawing.							
2										
2										

10-084-124 (REV. 12-84)

SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	PC	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

CC	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	28		Mask off Teflon pads and spray entire leaf assembly with polyurethane							
2			paint.							
2										
2	29		After paint has cured move part to assembly area. Remove masks from							
2			Teflon pads.							
2										
2										
2										
2										
2										
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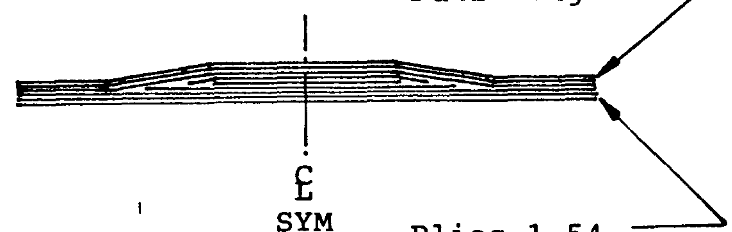
10-084-124 (REV. 12-64)

SHOP ORDER - SKETCH SHEET

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	DATE PART NUMBER	DWG. REV.	PLAN. REV.	SHEET OF PLAN. RESP.
							Rear Spring, Leaf #3	5127-0	N/C		

PLY LAY-UP DIAGRAM

Material: S2-glass fiber
Ply Thickness: .00865 in. (.22 mm) when cured
at 100 psi (690 KPa)



Ply No.	Length inches (mm)	Ply No.	Length inches (mm)
1-54	49.75 (1264)	76	7.60 (193)
55	28.00 (711)	77	9.68 (246)
56	27.04 (687)	78	11.75 (298)
57	26.08 (662)	79	13.21 (336)
58	25.25 (641)	80	14.04 (357)
59	24.42 (620)	81	14.87 (378)
60	23.59 (599)	82	15.70 (399)
61	22.76 (578)	83	16.53 (420)
62	21.93 (557)	84	17.36 (441)
63	21.10 (536)	85	18.19 (462)
64	20.27 (515)	86	19.02 (483)
65	19.44 (494)	87	19.85 (504)
66	18.61 (473)	88	20.68 (525)
67	17.78 (452)	89	21.51 (546)
68	16.95 (431)	90	22.34 (567)
69	16.12 (409)	91	23.17 (589)
70	15.28 (388)	92	24.00 (610)
71	14.45 (367)	93	24.83 (631)
72	13.62 (346)	94	25.66 (652)
73	12.79 (325)	95	26.49 (673)
74	10.71 (272)	96	27.32 (694)
75	8.64 (220)	97-150	49.75 (1264)

10-004-155

SHOP ORDER

DATE	SHEETS	OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Rear Spring, Leaf #4	5128-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs.; Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		Operations are identical to part number 5127-0. Mold produces one							
2			leaf at a time.							
2			Perform operations 01 through 29 shown for part no. 5127-0.							
2										
2										
2										
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2										

10-084-123 (REV. 12-64)

SHOP ORDER

DATE | SHEET | OF

SHOP ORDER NO.: | STARTING AREA: | SPLIT REFERENCE: | COMPLETION DATE (MONTH / DAY / YR.): | P C:

PART DESCRIPTION: Rear Spring, Leaf #5

PART NUMBER: 5129-0

DWG. REV.: N/C | PLAN. REV.: | PLAN. RESP.:

WORK CHARGE NUMBER: | QTY.: | SERIALIZATION: | MATERIAL AVAILABILITY (MONTH / DAY / YR.): | E.O.'S: | REASON FOR CHANGE:

TIME CARD CHARGE NO.: | RELEASED BY: | PLANNED BY: | DATE: | Q.C. APPROVAL: | DATE: | MASTER B.P.L. NO.: | NEXT ASSY NO.:

CHECK ONE
- ☐ SHOP ORDER NO. & OPER. NO.
- ☐ WORK CHARGE NO.

REVISED BY: | DATE: | Q.C. APPROVAL: | DATE:

MATERIAL DESCRIPTION: | SIMILAR TO: | I.W.A. NO.:

REVIEW AUTHORITY: NONE / ER / MR | INSP. LEVEL: | CHECK ONE: MEASURE (Est. Hrs. / Std. Hrs.) / Non-measure | TOTAL HRS.: SET-UP HRS. / RUN HRS.

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		Operations are identical to part number 5127-0. Mold produces two							
2			leaves at a time.							
2			Perform operations 01 through 29 shown for part no. 5127-0.							
2										
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2										

10-084-123 (REV. 12-64)

SHOP ORDER

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Spring Assembly, Rear	5185-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs. / Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		From storage take out existing steel spring assembly, Ordnance Part							
2			No. 7409613.							
2										
2	02		Disassemble steel spring. Set aside leaves numbers 1 and 2 (long							
2			leaves) in pairs. Also set aside center bolts. Return remaining							
2			parts to storage.							
2										
2	03		Clean steel leaves by light wiping with MEK. Do not remove paint.							
2										
2	04		Assemble steel leaves with composite leaves 5127-0, 5128-0, 5129-0, per							
2			drawing 5185-0. Make sure the bolt head is against the steel leaf.							
2			Place washer under nut and tighten nut. Torque nut to 30 - 35 ft-lbs							
2			4Ø to 47 Nm).							
2										
2	05		To keep leaves from moving during handling wrap a 3 inches (76 mm) wide							
2			strip of Kraft paper around all leaves 2 to 3 inches (50 to 75 mm) from							
2			the ends of the composite leaves. Secure paper by wrapping 2 inches							

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SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Spring Assembly, Rear	5185-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	05 (cont'd)		(50 mm) wide adhesive tape over paper strip.							
2										
2	06		Inspect assembly.							
2										
2	07		Place assembled spring in shipping container.							
2										
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10-084-124 (REV. 12-84)

APPENDIX B

FABRICATION PROCESS SHEETS

FRONT SPRING ASSEMBLY

SHOP ORDER

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Front Spring, Leaf #3	5137-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs.; Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

CC	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		Set up mold in press. Make sure all equipment is functioning properly.							
2										
2	02		Clean mold caul plates with MEK. Allow to dry for 5 minutes. Spray							
2			caul plate with Frekote 33 and heat to 250 degrees F (121 deg. C).							
2			Bake for 1 hour, cool. Repeat process two more times.							
2										
2	03		Remove R7269-S2 prepreg from cold storage. Verify acceptance and							
2			shelf life. Record roll and batch numbers. Let stand for 30 minutes							
2			at room temperature.							
2										
2	04		Place prepreg roll on cutting table. Be sure cutting table is clean.							
2										
2	05		Cut prepreg plies per engineering drawing (see attached sheet). Width							
2			of plies should be cut .25 inch (6 mm) less than the width of the mold							
2			cavity. Cut patterns so that the fibers are parallel to the sides.							
2										
2	06		Stack plies numbers 1 through 40 and place on the debulking tool. To							

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SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Front Spring, Leaf #3	5137-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	06	(cont'd)	prevent wrinkling of fibers in the curved contour of the layup, do not							
2			stack more than 10 plies (flat pattern) at a time in the debulking							
2			tool.							
2										
2	07		Cover with vacuum bag material and seal to tool with sealing tape.							
2			Attach vacuum port and hose. Apply vacuum (25 mm. Hg min.). Hold							
2			vacuum for 3.5 hours at room temperature.							
2										
2	08		Remove vacuum bag and resume layup of plies numbers 41 through 108.							
2			This layup provides the tapered thickness of the leaf. Make sure that							
2			all patterns are centered in the debulking mold and that the step							
2			between each pattern is of the same length on either side of the center							
2			line. To prevent wrinkling of the fibers in the curved contour of the							
2			layup, do not stack more than 10 plies (flat pattern) at a time in the							
2			debulking tool.							
2										
2	09		Cover with vacuum bag material and seal to tool with sealing tape.							
2			Repeat step 07.							
2										
2	10		Remove vacuum bag and resume layup of plies 109 through 148. To							
2			prevent wrinkling of the fibers, do not stack more than 10 plies (flat							

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SHOP ORDER CONTINUATION SHEET

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH DAY YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Front Spring, Leaf #3	5137-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	10 (cont'd)		pattern) at a time on the curved contour of the layup in the debulking							
2			tool.							
2	11		Cover layup with vacuum bag material and seal to tool with sealing							
2			tape. Repeat step 07.							
2										
2			* Note: If step 06 is performed at the start of the shift, steps 06							
2			through 11 can be completed in one day. Vacuum in step 11							
2			can then be left on over night.							
2										
2	12		Remove vacuum bag. Remove layup from debulking tool.							
2										
2	13		Weigh layup. Record weight. This is a check that the layup contains							
2			the correct number of plies.							
2										
2	14		Cut a piece of .010 inch (.25 mm) thick #7109 Teflon coated fabric of							
2			the same size as the mold cavity. Place on top of caul sheet in female							
2			half of mold. Make sure that both caul sheet and Teflon sheet are							
2			clean and free from foreign particles which may disturb the laminate							
2			surfaces.							
2										
2	15		Preheat mold to 180 degrees F (82 degrees C).							

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SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							ront Spring, Leaf #3	5137-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	16		Place layup in the female half of the mold.							
2										
2	17		Close mold. Apply 100 psig pressure.							
2			Hold for 40 minutes @ 180 degrees F (82 degrees C).							
2			Increase temperature to 205 degrees F (96 degrees C). Hold for 15							
2			minutes. Increase temperature to 230 degrees F (110 degrees C). Hold							
2			for 15 minutes. Increase temperature to 255 degrees F (124 degrees C).							
2			Hold for 15 minutes. Increase temperature to 280 degrees (138 degrees							
2			C) Hold for 3 hours Observe mold. Make sure mold closes properly.							
2										
2	18		Let mold cool to near room temperature while maintaining pressure.							
2										
2	19		Remove laminate from tool.							
2										
2	20		Transfer part to Machine shop.							
2										
2	21		Determine center line of laminate and mark with light color marking							
2			pencil across the width of the laminate. Do not use tool with sharp							
2			point to scribe center line.							
2										
2	22		Cut leaves per engineering drawing dimensions from laminate. Use							

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SHOP ORDER CONTINUATION SHEET

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Front Spring, Leaf #3	5137-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	22	(cont'd)	diamond coated circular saw.							
2										
2	23		Visually inspect cut surfaces for voids and flaws.							
2										
2	24		On accepted parts machine radius along all edges as called out on							
2			drawing.							
2										
2	25		Cut spacers and Teflon rubbing pads per drawing dimensions.							
2										
2	26		Bond spacers and pads to leaf.							
2			Bonding procedure:							
2			Etch surface to be bonded with TETRA-ETCH (manufactured by W. L.							
2			Gore & Associates, Flagstaff, AZ. Phone (602) 526-1290). Follow							
2			instructions on container. Clean off etchant with detergent							
2			mixture or alcohol. Apply adhesive, Scotch Weld 2216 (3M), to							
2			both surfaces. Use locating tool for bonding (Teflon pads move							
2			around when pressure is applied). Apply pressure and let stand							
2			for ½ hour at 175 degree F (79 degrees C), for several hours at							
2			room temperature. Wipe off excess adhesive.							
2										
2	27		Drill .53 inch (13.5 mm) diameter hole at center of leaf per drawing.							

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SHOP ORDER CONTINUATION SHEET

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Frong Spring, Leaf #3	5137-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	28		Mask off Teflon pads and spray entire leaf assembly with							
2			polyurethane paint.							
2										
2	29		After paint has cured move part to assembly area. Remove masks							
2			from Teflon pads.							
2										
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SHOP ORDER - SKETCH SHEET

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Front Spring, Leaf #3	5137-0	N/C		

DATE SHEET OF

PLY LAY-UP DIAGRAM

Material: S2-glass fiber
Ply thickness: .00865 in.(.22 mm) when cured at 100 psi (690 KPa)

Plies 1-40
Full length

Plies 109-148
Full length

Ply No.	Length inches	(mm)	Ply No.	Length inches	(mm)	Ply No.	Length inches	(mm)
1-40	54.0	(1372)	64	14.5	(368)	87	16.0	(406)
41	37.5	(953)	65	13.5	(343)	88	17.0	(432)
42	36.5	(927)	66	12.5	(318)	89	18.0	(457)
43	35.5	(902)	67	11.5	(292)	90	19.0	(483)
44	34.5	(876)	68	10.5	(267)	91	20.0	(508)
45	33.5	(851)	69	9.5	(241)	92	21.0	(533)
46	32.5	(826)	70	8.5	(216)	93	22.0	(559)
47	31.5	(800)	71	7.5	(191)	94	23.0	(584)
48	30.5	(775)	72	6.5	(165)	95	24.0	(610)
49	29.5	(749)	73	5.5	(140)	96	25.0	(635)
50	28.5	(724)	74	4.75	(121)	97	26.0	(660)
51	27.5	(699)	75	4.25	(108)	98	27.0	(686)
52	26.5	(673)	76	5.0	(127)	99	28.0	(711)
53	25.5	(648)	77	6.0	(152)	100	29.0	(737)
54	24.5	(622)	78	7.0	(178)	101	30.0	(762)
55	23.5	(597)	79	8.0	(203)	102	31.0	(787)
56	22.5	(572)	80	9.0	(229)	103	32.0	(813)
57	21.5	(546)	81	10.0	(254)	104	33.0	(838)
58	20.5	(521)	82	11.0	(279)	105	34.0	(864)
59	19.5	(495)	83	12.0	(305)	106	35.0	(889)
60	18.5	(470)	84	13.0	(330)	107	36.0	(914)
61	17.5	(445)	85	14.0	(356)	108	37.0	(940)
62	16.5	(419)	86	15.0	(381)	109-148	54.0	(1372)
63	15.5	(394)	87	16.0	(406)			

10-004-155

SHOP ORDER

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Front Spring, Leaf #4	5138-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs.; Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP / RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		Operations are identical to part number 5137-0. Perform operations							
2			01 through 29 shown for part no. 5137-0							
2										
2										
2										
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2										

10-084-123 (REV. 12-64)

SHOP ORDER

DATE SHEET OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE (MONTH / DAY / YR.)	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
					Spring Assembly, Front	5186-0	N/C		

WORK CHARGE NUMBER	QTY.	SERIALIZATION	MATERIAL AVAILABILITY (MONTH / DAY / YR.)	E.O.'S	REASON FOR CHANGE

TIME CARD CHARGE NO.	RELEASED BY	PLANNED BY	DATE	Q.C. APPROVAL	DATE	MASTER B.P.L. NO.	NEXT ASSY NO.
CHECK ONE ☐ SHOP ORDER NO. & OPER. NO. ☐ WORK CHARGE NO.		REVISED BY	DATE	Q.C. APPROVAL	DATE		

MATERIAL DESCRIPTION	SIMILAR TO	I.W.A. NO.	REVIEW AUTHORITY (NONE / ER / MR)	INSP. LEVEL	CHECK ONE (MEASURE: Est. Hrs. / Std. Hrs.; Non-measure)	TOTAL HRS. (SET-UP HRS. / RUN HRS.)

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	01		From storage take out existing steel spring assembly, Ordinance Part							
2			No. 7411110.							
2										
2	02		Disassemble steel spring. Set aside leaves numbers 1 and 2 (long							
2			leaves) in pairs. Also set aside top leaf (rebound leaf, tapered							
2			tips), one of the short leaves (15.75 inches (400 mm) long, and the							
2			center bolt. Return the remaining parts to storage.							
2										
2	03		Clean steel leaves by light wiping with MEK. Do not remove paint.							
2										
2	04		Have machine shop machine tips of the short leaf per the attached							
2			sketch.							
2										
2	05		Paint short steel leaf with rust preventing primer. Match color of							
2			other steel leaves.							
2										
2	06		Assemble steel leaves with composite leaves 5137-0 and 5138-0 per							

10-084-123 (REV. 12-64)

SHOP ORDER CONTINUATION SHEET

DATE | SHEET | OF

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Spring Assembly, Front	5186-0	N/C		

C C	OPER. NO.	STA. NO.	OPERATION DESCRIPTION	OPR. DWG.	STAMP PROD.	STAMP INSP.	SET UP RUN TIME	CREW	TOOL NAME AND NUMBER	TOOL AVAIL. DATE
2	06 (cont'd)		drawing 5186-0. Make sure the bolt is installed with the head							
2			against the rebound leaf. Tighten nut. Torque nut to 30 - 35 ft-lbs							
2			(41 to 47 Nm).							
2										
2	07		To keep leaves from moving during handling wrap a 3 inch (76 mm)							
2			wide strip of Kraft paper around all leaves 2 to 3 inches (50 to 75							
2			mm) from the ends of the composite leaves. Secure paper by wrapping							
2			2 inches wide adhesive tape over paper strip.							
2										
2	08		Inspect assembly.							
2										
2	09		Place assembled spring in shipping container.							
2										
2										
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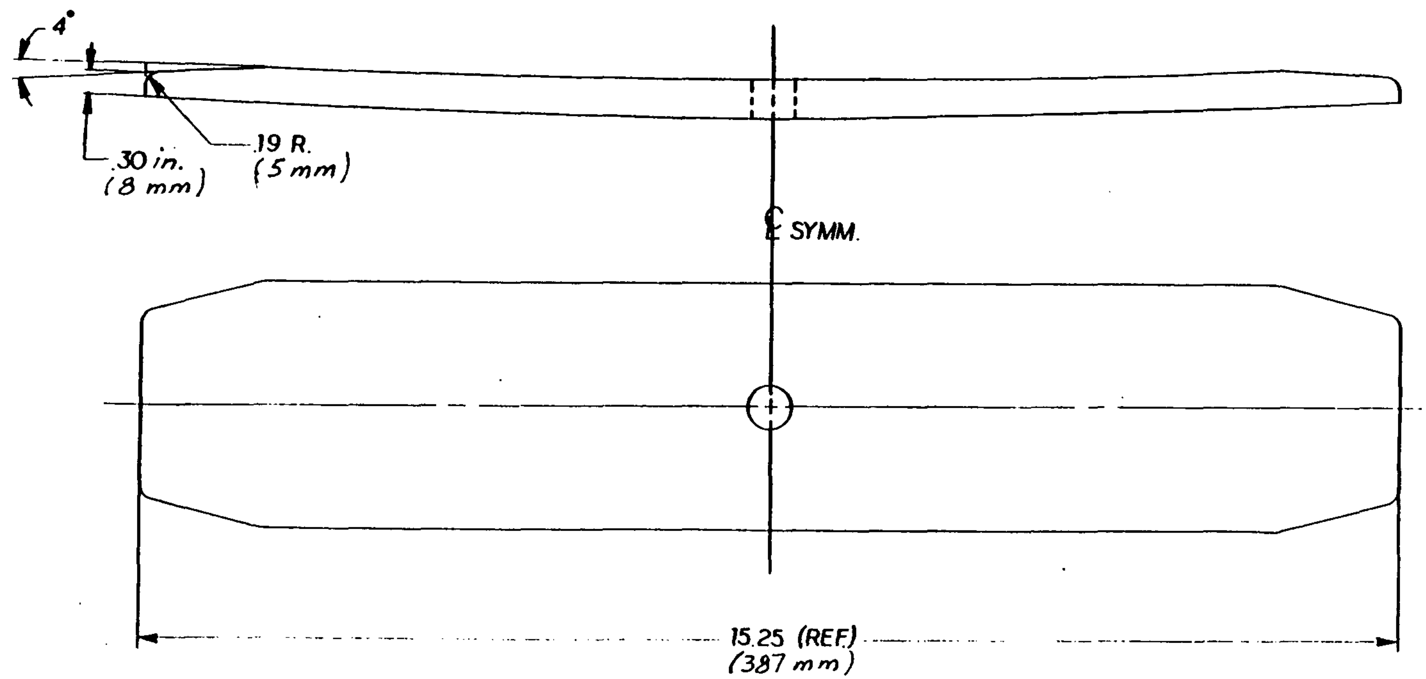
2										
2										
2										

SHOP ORDER - SKETCH SHEET

SHOP ORDER NO.	STARTING AREA	SPLIT REFERENCE	COMPLETION DATE MONTH	DAY	YR.	P C	PART DESCRIPTION	DATE PART NUMBER	DWG. REV.	PLAN. REV.	PLAN. RESP.
							Spring Assembly, Front	5186-0	N/C		



LEAF NO. 10 MODIFICATION

10-004-155

APPENDIX C

COST SUMMARY

DD FORM 633

DEPARTMENT OF DEFENSE **CONTRACT PRICING PROPOSAL**	FORM APPROVED OMB NO 22 R0381

This form is for use in procurements when submission of cost or pricing data is required (See DAR 3-807)

NAME ADDRESS AND TELEPHONE NUMBER OF ORGANIZATIONAL ELEMENT RESPONSIBLE FOR SUPPORTING PROPOSAL

CIBA-GEIGY CORPORATION
COMPOSITE MATERIALS DEPARTMENT
10910 Talbert Ave.
Fountain Valley, CA 92708

TYPE OF CONTRACT

PLACE(S) AND PERIOD(S) OF PERFORMANCE

TOTAL COST

PROFIT/FEE

TOTAL

TYPE OF PROCUREMENT ACTION

☐ NEW PROCUREMENT ☐ LETTER CONTRACT ☐ OTHER *(Specify)*
☐ CHANGE ORDER ☐ UNPRICED ORDER
☐ PRICE REVISION/REDETERMINATION

LINE ITEM NO	IDENTIFICATION NOTE List and reference the identification, quantity and total price proposed for each contract line item. A line item cost breakdown supporting this recap is required unless otherwise specified by the Contracting Officer. *(Attach continuation page if required)*	QUANTITY	TOTAL PRICE	REF
	SEE SECTION 8. OF REPORT			

I IF YOUR ACCOUNTS AND RECORDS HAVE BEEN REVIEWED IN CONNECTION WITH ANY GOVERNMENT CONTRACT (PRIME OR SUBCONTRACT), GRANT OR PROPOSAL WITHIN THE PAST 3 YEARS BY A GOVERNMENT AGENCY OTHER THAN IRS OR GAO, PROVIDE NAME, ADDRESS AND TELEPHONE NUMBER BELOW

CONTRACT ADMINISTRATION OFFICE	AUDIT OFFICE

II WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS WORK?
☐ YES ☐ NO *IF YES, IDENTIFY*

III DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?
☐ YES ☐ NO *IF YES, IDENTIFY* ☐ ADVANCE PAYMENTS ☐ PROGRESS PAYMENTS *OR* ☐ GUARANTEED LOANS

IV HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR THE SAME OR SIMILAR ITEMS WITHIN THE PAST 3 YEARS?
☐ YES ☐ NO *IF YES, IDENTIFY ITEM(S), CUSTOMER(S) AND CONTRACT NUMBER(S)*

V IS THIS PROPOSAL CONSISTENT WITH YOUR ESTABLISHED ESTIMATING AND ACCOUNTING PRACTICES AND PROCEDURES AND DAR SECTION XV COST PRINCIPLES?
☐ YES ☐ NO *IF NO, EXPLAIN*

VI COST ACCOUNTING STANDARDS BOARD (CASB) DATA (PUBLIC LAW 91 379 AS AMENDED)

a. WILL THIS PROCUREMENT ACTION BE SUBJECT TO CASB REGULATIONS?
☐ YES ☐ NO *IF NO EXPLAIN*

b. HAVE YOU SUBMITTED A CASB DISCLOSURE STATEMENT (CASB DS 1 or 2)?
☐ YES ☐ NO *IF YES, SPECIFY THE OFFICE TO WHICH SUBMITTED AND IF DETERMINED TO BE ADEQUATE*

c HAVE YOU BEEN NOTIFIED THAT YOU ARE OR MAY BE IN NONCOMPLIANCE WITH YOUR DISCLOSURE STATEMENT OR COST ACCOUNTING STANDARDS?
☐ YES ☐ NO *IF YES, EXPLAIN*

d IS ANY ASPECT OF THIS PROPOSAL INCONSISTENT WITH YOUR DISCLOSED PRACTICES OR APPLICABLE COST ACCOUNTING STANDARDS?
☐ YES ☐ NO *IF YES EXPLAIN*

This proposal is submitted in response to (RFP, contract/mod, etc.) ____________________
____________________ and reflects our best estimates and/or actual costs as of this date, in accordance with the instructions of this form

TYPED NAME AND TITLE	SIGNATURE
K.R. BERG Manager, Composite Engineering	KRBerg

NAME OF FIRM	DATE OF SUBMISSION
CIBA-GEIGY CORPORATION COMPOSITE MATERIALS DEPARTMENT	June 13, 1984

DD FORM 633
1 April 79

Previous edition is obsolete. Replaces DD Forms 633-1 through 5, Apr 68 and DD Form 633-6, Jun 72, which are obsolete.

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